ADJUSTING SLASH PINE GROWTH AND YIELD FOR SILVICULTURAL TREATMENTS

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Abstract—With intensive silvicultural treatments such as fertilization and competition control now commonplace in today's slash pine (*Pinus elliottii* Engelm.) plantations, a method to adjust current growth and yield models is required to accurately account for yield increases due to these practices. Some commonly used ad-hoc methods, such as raising site index, have been found to inadequately account for yield responses seen in designed studies. Based on data from a Plantation Management Research Cooperative (PMRC) slash pine site preparation study, a PMRC slash pine improved planting stock – vegetation control study, and a PMRC slash pine mid-rotation release study, two model forms have been fit to account for fertilization, competition control, bedding, and mid-rotation release. These models are used to adjust current dominant height and basal area equations for the various treatments. The model forms, different treatment response patterns, and magnitude of each treatment response are presented.

INTRODUCTION

Silvicultural treatment options have grown tremendously over the last 25 years. After the loss of 2-4,5 -T in the late 1970s, several new herbicides were labeled for forestry use. The result was chemistry that was previously unavailable is now usable for control competing vegetation at site preparation, for woody release, and for herbaceous weed control. Research over the same time period documented that large yield increases were possible when vegetation control was used on research plots. Forest nutrition work on slash pine at the University of Florida and on loblolly pine at North Carolina State University also documented the high probability of yield gains in plantations from nutritional supplements. Again, most of the empirical information came from research plots, not from operational stands. Regardless, operational fertilization grew to more than 1,000,000 acres in the Southeast by the year 2000.

A problem with both vegetation control and forest fertilization is that the available yield models have not typically handled the amount and timing of the silvicultural response so that financial analyses of the investment could be reliably conducted. Whether it is nutritional amendments or the control of competing vegetation, the change in stand growth must be analyzed to determine if the treatment is financially positive. This paper presents an accurate method to account for these silvicultural treatments that is not overly complex so all forest managers can make sound decisions when faced with these situations.

SILVICULTURAL ADJUSTMENT METHODS

Various methods of accounting for the effects of silvicultural treatments on pine growth and yield have been explored over the years. One of the most rudimentary of these methods is the adjustment of site index. Although generally inaccurate, this method is commonly used today in at least two variations by forest managers. The first variation simply involves increasing site index by the amount equal to the expected dominant height gains from the silvicultural treatment. An example would be increasing base age 25 site index from 62 feet to 66 feet because the forest manager estimates that a fertilization treatment will result in an increase in dominant height at age 25 of 4 feet. Although this seems like a logical method of accounting for a treatment, this assumes that a treatment will cause an anamorphic change to the dominant height growth curve. Based on the current study, this is an inaccurate assumption. This method of adjustment also ignores the fact that many treatments increase diameter growth, and therefore yield, more than the increase in site index estimates.

The second variation of this method has been used in an attempt to more accurately model the effects of the silvicultural treatments on volume growth, not just height growth. In this method, users adjust site index to whatever value is needed to increase volume by some expected amount for a chosen time period. An example of this method would be adjusting site index to cause an increase in volume of 9.6 tons after 8 years. The 9.6 tons is based on the assumption that a treatment will cause an average increase of 1.2 tons per year over an 8 year period. Although this method does make an attempt to more directly quantify the effects of silvicultural treatments on volume, it still makes the assumption that all treatments will cause an anamorphic change in tree growth. This method generally results in large over-predictions in weight or volume at rotation age when used to model site preparation treatments.

Newer methods of accounting for silvicultural treatments involve using flexible mathematical equations as additive response terms to the current pine growth and yield models. Two such equations are presented in this paper.

DATA

Three PMRC studies were used to examine the effects of vegetation control and fertilization treatments on the growth and yield of slash pine plantations. All study installations were located in the flatwoods region of the lower Coastal Plain throughout southern Georgia and northern Florida.

Slash Pine Site Preparation Study

The slash pine site preparation study was established in 1979 at 20 locations. The 20 locations were originally stratified

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equally over 4 soil groups: poorly drained nonspodosol, somewhat poorly to moderately well drained nonspodosol, poorly to moderately well-drained spodosol with an underlying argillic horizon, and poorly- to moderately well-drained spodosol without an underlying argillic horizon. Half acre treatment plots, with a maximum site index variance of 5 feet, were installed at each site. Average site index across installations ranged from 54 to 80 feet. The following 11 treatments were applied at each location:

1. Control (harvest and plant, no site preparation) CNTL
2. Chop (single pass with a rolling drum chopper) UCHP
3. Chop, fertilize FCHP
4. Chop, burn (chop followed by a broadcast burn) UCHB
5. Chop, burn, fertilize FCHB
6. Chop, burn, bed (treatment 4 followed by a double-pass bed) UCBB
7. Chop, burn, bed, fertilize FCBB
8. Chop, burn, herbicide (treatment 4 followed by complete vegetation control) UCBH
9. Chop, burn, herbicide, fertilize FCBH
10. Chop, burn, bed, herbicide (treatment 6 followed by complete vegetation control) UBHB
11. Chop, burn, bed, herbicide, fertilize FBHB.

Fertilizer was applied to the selected treatment plots after the 1st, 12th, and 17th growing seasons. Height and diameter measurements were made at ages 2, 5, 8, 11, 14, 17, 20, and 23. Due to the design of the study, it is possible to isolate the effect of treatments. For example, the difference in yield between treatment 8 (UCBH) and treatment 4 (UCHB) is due to the addition of vegetation control.

Slash Pine Improved Planting Stock - Vegetation Control Study

The slash pine improved planting stock – vegetation control study was established in the planting seasons of 1986 and 1987 at a total of 19 locations. Six top-ranked genetically improved seed families were selected by PMRC cooperators for inclusion in the study. Unimproved seed was obtained from the same region encompassed by the study. Bulk lot improved seed stock was obtained by mixing equal amounts of the six selected seed families. The following six treatments were included at each installation:

1. Unimproved stock, no vegetation control (UNC)
2. Unimproved stock, complete vegetation control (UCC)
3. Bulk lot improved stock, no vegetation control (BNC)
4. Bulk lot improved stock, complete vegetation control (BCC)
5. Single family improved stock, no vegetation control (SNC)
6. Single family improved stock, complete vegetation control (SCC).

One single family was randomly assigned to each installation, so on average each single family was planted at three installations. The two levels of vegetation control were either no control or complete control of all competing vegetation. Complete vegetation control was obtained by killing woody vegetation with prescribed herbicides prior to planting, by spraying sulfometuron methyl in early spring in each of the first three growing seasons, and by directed application of glyphosate and triclopyr as needed during the growing season. Height and diameter measurements were made at ages 3, 6, 9, 12, and 15. Again, the design of the study allows for estimation of the effects of vegetation control. The difference between UNC and UCC, the difference between BNC and BCC, and the difference between SNC and SCC all estimate the influence of vegetation control. The design also allows for a test of the interaction of vegetation control and level of genetic improvement. That interaction was not significant so the vegetation control effect was estimated using all three comparisons.

Slash Pine Midrotation Release Study

The slash pine midrotation release study was established in 1976 at 36 locations. Paired permanent plots were installed in existing 9- to 15-year-old slash pine plantations with considerable competing vegetation and at least 400 evenly spaced trees per acre. Plots were carefully located to match closely on numbers of trees per acre, site index, and basal area per acre before treatment. No vegetation control was performed on the control portion of the paired plots. All competing vegetation was cut at ground level and left on site on the treatment portion of the paired plots. Severed stems were retreated with herbicide soon after resprouting and periodic competition control was performed as needed. On this study, the vegetation control response was estimated as the difference between the yields on the paired plots.

TREATMENT RESPONSE PATTERNS

Four general response patterns (fig. 1) to silvicultural treatments have been identified, types A, B, C and D (Hughes and others 1979, Morris and Lowery 1988, NCSFNC 1995). Type A responses occur when growth gains on treated stands continue to increase throughout the rotation. This type of response is commonly associated with anamorphic increases in height growth. Type B responses occur when growth gains achieved early during the response period are maintained but do not increase after an initial response period. Type C responses occur when the early growth gains are subsequently lost and eventually converge with the untreated stand.

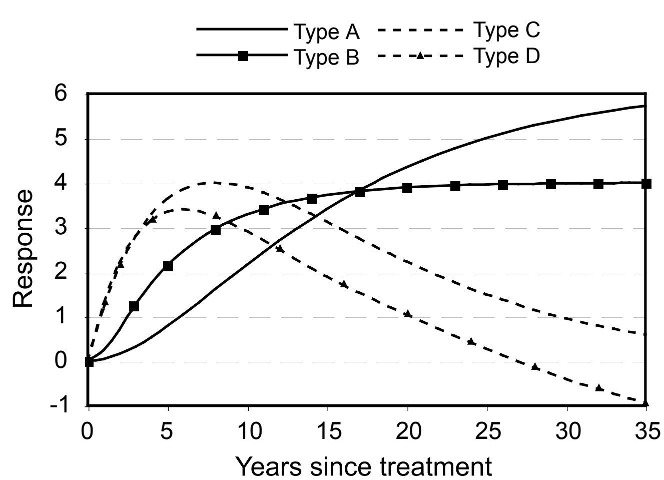

Figure 1—Four general silvicultural response patterns.

Type D responses are similar to type C response except that the treated stand actually falls below the level of the untreated stand.

MODEL DEVELOPMENT

Based on the treatments examined in this study, two response patterns (Type B and C) were observed and modeled.

Type C Response

Pienaar and Rheney (1995) described a flexible equation form to model a type C response:

$$R = b_1 \left(Y_{st}\right) e^{-b_2 \left(Y_{st}\right)} \tag{1}$$

where

R = treatment response,

b_1,b_2 = parameters that define the response curve, and

Y_{st} = year since treatment.

The maximum response occurs ($1/b_2$) years after the treatment, and the magnitude of the maximum response is defined by $(b_1/b_2)e^{-1}$. Based on this, the parameters can be defined empirically as:

$$b_2 = 1/\left(Y_{st}\right)_{\max}$$

$$b_1 = R_{\max} \cdot b_2 \cdot e^{(1)}$$

where

$(Y_{st})_{max}$ = years until maximum treatment response

R_{max} = maximum treatment response.

Type B Response

The type B response can be modeled by the following equation (Personal communication. 2004. Leon Pienaar, Professor (retired), 525 Pine Forest, Athens, GA 31029):

$$R = R_{\max}\,(1 - e^{-b \cdot Y_{st}}) \tag{2}$$

where

all variables are as defined previously. The user will provide treatment age, the maximum expected treatment response, and the years until 90 percent of the maximum treatment response occurs so that:

$$b = \frac{-\ln(1-.9)}{Y_{st(.9\max)}}$$

where

$Y_{st(.9max)}$ = years until 90 percent of the maximum treatment response occurs.

MODEL USE

The previous models are used as an additive term to current "base" models. General use includes calculating dominant height with the current model and using the appropriate response model to calculate the treatment response at a given age. This dominant height response is added to the calculated dominant height, which is put into the "base" basal area model. Depending on the treatment, an additional basal area response may be warranted. If needed, the appropriate basal area response model is used to calculate an additional basal area treatment response that is added to the calculated basal area. The adjusted dominant height and basal area are then used in the whole stand volume or weight equation to calculate an estimate of volume or weight after treatment.

Based on data from the previously mentioned designed studies, it was determined that low sites generally respond more to silvicultural treatments than high sites. To account for this, maximum responses for site index (base age 25) 50 and 80 are presented. Simple linear interpolation can be used to calculate a maximum treatment response for a given site. Also, since spodosol soils were observed to respond more to silvicultural treatments than nonspodosol soils, separate responses are presented.

When modeling multiple treatments at the same time or repeated treatments over time, it is not uncommon to see less than additive responses from the multiple treatments. An example is when modeling a silvicultural treatment that includes a combination of fertilization and vegetation control. On spodosol soils, the benefits of each treatment are not additive and can be accounted for by using only the dominant height gains associated with fertilization and vegetation control. On nonspodosol soils, the effect of both treatments are additive. In cases where multiple fertilizations are being modeled, the full benefit of the repeated fertilizations is not realized. To account for this, we used 75 percent of the maximum response from the first fertilization for subsequent fertilization treatments.

Response Values

Response type, maximum response, and years until maximum response (or years until 90 percent of maximum response for type B responses) are presented in table 1 for 4 treatments as estimated from 3 studies.

Model Usage Example

Assume we have a slash pine stand with a base age 25 site index of 62 on nonspodosol soils. We plan on fertilizing the stand at ages 5 and 15 and want to know the response we can expect from the repeated fertilization treatments. Based on the data in the response table, we will use a type B dominant height response and a type C basal area response. The maximum dominant height response from the first fertilization can be calculated as 1.1 feet by use of linear interpolation. The table indicates this will occur 8 years after treatment. The maximum dominant height response from the second fertilization will be 75 percent of the maximum response from the first fertilization, or 0.83 feet. The maximum basal area response is calculated in the same manner. We expect a maximum basal area response of 2.2 square feet from the first fertilization and a maximum basal area response of 1.65 square feet, or 75 percent of the response from the first fertilization, from the second fertilization. These basal area responses are in addition to the basal area response obtained from the height response. This will occur 10 years after the fertilization treatments. Based on this information we can calculate the fertilization treatment response at any age, as below for ages 8 and 20.

The dominant height response at age 8 is calculated as:

$$b = \frac{-\ln(1-.9)}{Y_{st(.9\max)}} = \frac{-\ln(.1)}{8} = 0.2878$$

$$R = R_{\max}\,(1 - e^{-b \cdot Y_{st}}) = 1.1(1 - e^{-.2878 \cdot 3}) = 0.64 \text{ ft.}$$

Table 1—Dominant height (feet) and basal area (square feet per acre) response types and values for slash pine

	Nonspodosol			Spodosol		
Treatment	Response type	SI=50 response	SI=80 response	SI=50 response	SI=80 response	Years to max response
Dominant height						
Bedding	C	3.0	1.0	4.5	2.5	8.0
Veg. control	B	6.0	3.0	8.0	4.0	12.0
Fertilization	B	1.5	0.5	3.0	2.0	8.0
Release	B	2.0	1.0	2.0	1.0	10.0
Basal area						
Bedding	C	4.0	3.0	4.0	3.0	5.0
Veg. control	B	0.0	0.0	6.0	6.0	12.0
Fertilization	C	3.0	1.0	3.0	1.0	10.0
Release	B	6.0	6.0	6.0	6.0	10.0

To calculate the dominant height response at age 20 the response from both the first and second fertilizations must be calculated as follows:

$$R_{fert1} = R_{\max}(1 - e^{-b \cdot Y_{st}}) = 1.1(1 - e^{-.2878 \cdot 15}) = 1.09 \text{ ft.}$$

$$R_{fert2} = R_{\max}(1 - e^{-b \cdot Y_{st}}) = 0.83(1 - e^{-.2878 \cdot 5}) = 0.63 \text{ ft.}$$

The total dominant height response at age 20 from the fertilization treatments is 1.72 feet. Dominant height response over time can be seen in figure 2.

The basal area response at age 8 is calculated as:

$$b_2 = 1/(Y_{st})_{\max} = 1/10 = 0.1$$

$$b_1 = R_{\max} \cdot b_2 \cdot e^{(1)} = 2.2 \cdot 0.1 \cdot e^{(1)} = 0.598$$

$$R = b_1 (Y_{st}) e^{-b_2 (Y_{st})} = 0.598(3) e^{-0.1(3)} = 1.329 \text{ ft.}^2$$

To calculate the basal area response at age 20, the b_1 coefficient must be recalculated because it is a function of the maximum response of the second fertilization. The b_2 coefficient remains the same.

$$b_1 = R_{\max} \cdot b_2 \cdot e^{(1)} = 1.65 \cdot 0.1 \cdot e^{(1)} = 0.4485$$

$$R_{fert1} = b_1 (Y_{st}) e^{-b_2 (Y_{st})} = 0.598(15) e^{-0.1(15)} = 2.00 \text{ ft.}^2$$

$$R_{fert2} = b_1 (Y_{st}) e^{-b_2 (Y_{st})} = 0.4485(5) e^{-0.1(5)} = 1.36 \text{ ft}^2$$

The total basal area response at age 20 from the fertilization treatments is 3.36 square feet. Basal area response over time can be seen in figure 3. Note that the majority of the basal area response results from the increase in dominant height from the repeated fertilizations. The resulting increase in green weight can be seen in figure 4. The green weight growth curves of the treated and untreated stands can be seen in figure 5.

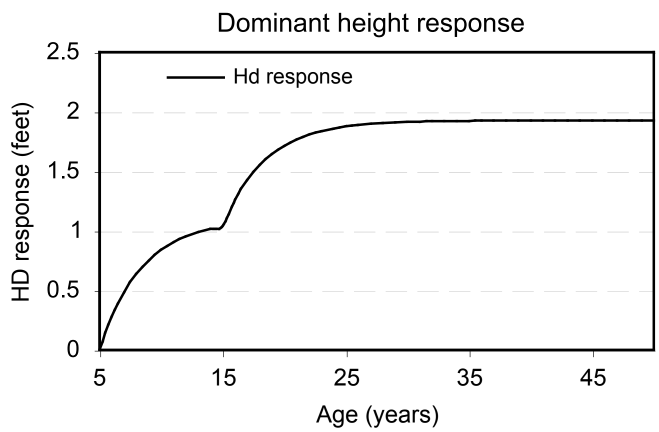

Figure 2—Expected dominant height (feet) response over time for two fertilization treatments on a slash pine stand.

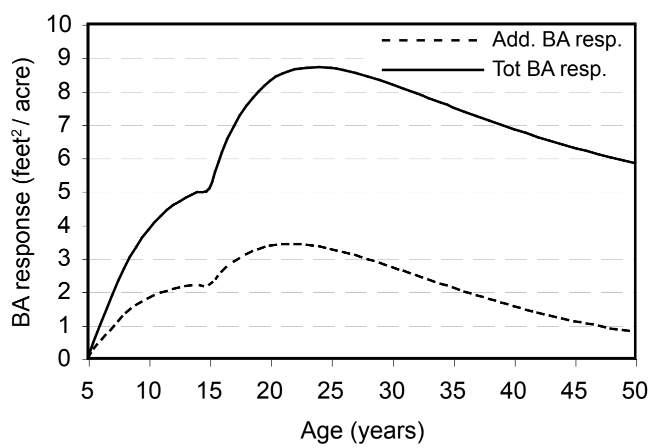

Figure 3—Expected basal area response (square feet per acre) in addition to basal area response from dominant height increase and total basal area response over time for two fertilization treatments on a slash pine stand.

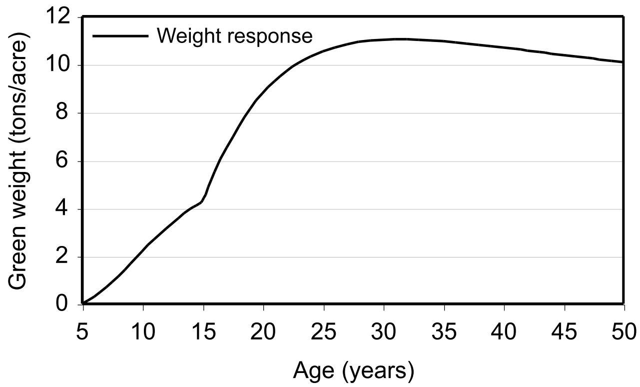

Figure 4—Expected green weight (OB) response (tons per acre) over time for two fertilization treatments on a slash pine stand.

Figure 5—Green weight (OB) growth (tons per acre) over time for a twice fertilized and an unfertilized slash pine stand.

CONCLUSIONS

The presented models give forest managers a flexible tool for modeling silvicultural treatments on planted slash pine stands. These response values are based on results from designed studies and are good average values for most stands. If a forest manager feels that these responses are not accurate for a particular stand, different response values can be used to reparameterize these equations. Caution should be used when adjusting response values and final volume or weight responses should be scrutinized to ensure reasonable growth responses.

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