APPLYING THE AGE-SHIFT APPROACH TO MODEL RESPONSES TO MIDROTATION FERTILIZATION

Colleen A. Carlson, Thomas R. Fox, H. Lee Allen, and Timothy J. Albaugh[1]

Abstract—Growth and yield models used to evaluate midrotation fertilization economics require adjustments to account for the typically observed responses. This study investigated the use of age-shift models to predict midrotation fertilizer responses. Age-shift prediction models were constructed from a regional study consisting of 43 installations of a nitrogen (N) by phosphorus (P) factorial experiment established in midrotation loblolly pine stands in the Southeast United States. Ten years of data indicated that, with time after fertilization, the age-shifts increased to an asymptote. The asymptote and the time to reach it were functions of the rate of fertilizers applied, as well as initial stand parameters including initial stocking, dominant height, stand age and basal area. The methodology was verified with an independent data set.

INTRODUCTION

Midrotation fertilization responses need to be included in growth and yield models in order to make economic analyses and predict stand yield. Approaches used to model midrotation fertilization responses have included adjusting site index (SI) (Daniels and Burkhart 1975), adding a term associated with the response to a yield function (Amateis and others 2000, Pienaar and Rheney 1995), using a multiplier to adjust the growth rate of the trees according to the elements (both rate and form) that were applied (Hynynen and others 1998), or "hard wiring" the fertilizer response into the growth and yield model (Bailey and others 1989, Martin and others 1999). We investigated the use of age-shifts to model midrotation fertilizer responses.

Miller and Cooper (1973) originally suggested that midrotation fertilizer responses are analogous to stand development acceleration through time. Midrotation applications of N and P generally result in Type B responses (Nilsson and Allen 2003) in the Southeastern United States (Fox and others 2007). That is, the growth rate of the treated trees increases relative to the untreated ones for a short period of time, after which all trees have similar growth trajectories. Consequently the treated trees reach a given height, diameter or volume earlier, thus reducing the rotation length. These responses are compatible with the age-shift concept. The age-shift approach has been used to evaluate various silvicultural treatments (Kimberley and others 2004, Lauer and others 1993, Snowdon 2002, South and others 2006), and the methodology for calculating age-shifts has been discussed extensively by South and others (2006). The aim of the current study was to use this approach on data from two regional fertilizer trial series.

METHODS

Data from the Forest Nutrition Cooperative's Regionwide 13 trial series were used to construct age-shift prediction models. The Regionwide 13 study was a four (0, 100, 200, and 300 pounds-N/acre applied as urea [46 percent]) by three (0, 25, and 50 pounds-P/acre applied as triple superphosphate (20 percent)) factorial experiment replicated two or four times in 43 midrotation loblolly (*Pinus taeda*) stands aged between 9 and 19 years. Data used to validate the model was from the Forest Nutrition Cooperative's Regionwide 15 trial series which consisted of three or four replicates of a variable treatment matrix that included two treatments (an untreated control and 200 pounds-N/acre applied with 50 pounds-P/acre) common to the Regionwide 13 trials and had been established in stands aged between 11 and 25 years.

Age-shifts were determined using the basal area mean response for each treatment at each site. The response was defined as the difference in basal area at a particular time after fertilization and the value prior to fertilization. The age-shift was calculated by regressing control plot basal area against years since fertilization. The fertilizer response data was then substituted into the derived regression equation in order to estimate the time required for an untreated stand to grow to the equivalent basal area. Finally, the age-shift was calculated by subtracting the number of years since fertilization from the estimated time required to reach that level of basal area. The shapes of the fertilized and control treatment responses were verified as being similar. This is a critical assumption of the methodology.

A model was constructed to predict the Regionwide 13 basal area age-shifts based on the time since fertilization, the treatments, and the initial stand parameters. This model was then used to predict the age-shift associated with basal area for the Regionwide 15 data set. The correlation between the actual age-shift and the predicted age-shift in the Regionwide 15 data was examined with the Pearson correlation coefficient. The difference between the actual age-shift in the Regionwide 15 data set and the predicted age-shift based was then calculated. This difference was subject to a t-test, with the null hypothesis being that the difference should be zero. This would be the case if the model predicted 100 percent accurately.

All statistical and data analyses were performed using SAS (SAS Institute 2005).

[1]Research Associate and Associate Professor, Forest Nutrition Cooperative, Virginia Polytechnic Institute and State University, Blacksburg, VA; Professor and Senior Research Associate, Forest Nutrition Cooperative, North Carolina State University, Raleigh, NC, respectively.

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RESULTS AND DISCUSSION

The mean basal area age-shifts determined from the Regionwide 13 data for each treatment combination are shown in figure 1. When both N and P are applied, the age-shifts increase to an asymptote as the time after fertilization increases, and the magnitude of the asymptote and the time to reach it are functions of the applied nutrients and the application rate. Where no P was applied, the age-shift is transient, peaking at a lower level, and then decreasing. The age-shift data shows little response to P alone, but an increasing response to increasing rates of N, with significantly larger responses when 200 or 300 pounds/acre of N is applied in the presence of P. This is similar to reports in the literature (Amateis and others 2000, Hynynen and others 1998). However, there is little difference in response when P is applied at 25 or 50 pounds/acre.

The basal area age-shifts calculated from the two different trial series for the 200 pounds-N/acre plus 50 pounds-P/acre treatment follow the same trend over time (table 1). There were no significant differences in the estimates made from the different data sets within a given time period indicating the robustness of the technique.

The model that was derived from the Regionwide 13 is given below (parameter estimates in table 2).

$$\text{basal area} = d_0 . e^{(1-(d5^*\text{Nrate}))} . (\text{YST}^{d1}) . e^{(\text{YST}.(d2+(d3^*\text{Pindi})))} . (\text{TPA0}/1000)^{d4} . (\text{Ht}_{\text{dom0}}/\text{age0})^{d6} \quad (1)$$

where:
basal area is the age-shift for basal area; N rate is the rate of N application (pounds/acre); YST is the years since application; Pindi is an indicator variable where 1 denotes that P was applied and 0 elsewhere; and TPA0, Ht_{dom0}, and age0 are respectively, the trees per acre, dominant height (feet), and age at time of fertilization.

Two Regionwide 15 studies were poorly predicted by the derived model. These studies had shown unusually large gains from fertilization with a 53 and 70 percent improvement in basal area which equated to an age-shift of 5.22 and 7.33 years respectively. These results indicate a Type A response to the fertilizer application which apparently changed the carrying capacity of the site. When excluding these two studies in the basal area predictions, a significant ($p<0.0001$) Pearson correlation coefficient of 0.74 was found between the predicted and the actual age-shifts.

The mean difference between the actual age-shift in the Regionwide 15 data set and the predicted age-shift based on the model was determined to be -0.10 years. The null hypothesis from the t-test was rejected indicating that the model significantly over-predicted basal area. Although the margin of over-prediction was small, it indicates that further model refinement is necessary.

CONCLUSIONS

We conclude that the use of the age-shift approach is a viable option for modeling midrotation fertilizer responses. The age-shift can be included in stand level projection functions by simply adding the relevant age-shift to the projected age. The approach can be considered to have biological meaning if one considers that the response to the midrotation application of N and P accelerates stand development. The fact that the age-shifts can readily be

Table 1—Comparisons of the basal area age-shifts calculated from the Regionwide 13 and 15 trial series for the 200 pounds-N/acre plus 50 pounds-P/acre treatment

Years since treatment	Regionwide 13			Regionwide 15		
	Mean	95 % confidence limits		Mean	95 % confidence limits	
2	0.76 (n=43)	0.60	0.92	0.91 (n=24)	0.61	1.22
4	1.41 (n=38)	0.97	1.86	1.73 (n=23)	1.24	2.21
6	1.85 (n=31)	1.16	2.54	1.96 (n=16)	1.08	2.83
8	2.17 (n=25)	1.39	2.95	2.28 (n=13)	1.00	3.55
10	2.09 (n=19)	0.94	3.25			

The number of observations is given in parentheses adjacent to the mean.

The 95% confidence intervals indicate that there are no significant differences between the age-shifts associated with the different data sets at each time point. The shaded cells indicate that there was insufficient data to construct a confidence interval (i.e., n < 2).

Table 2—Parameter estimates for the model

Parameter	Estimate	Approx Standard Error	Lower CL	Upper CL
d0	0.0383	0.00676	0.025	0.0515
d1	1.7701	0.2285	1.3219	2.2184
d2	-0.3852	0.0449	-0.4733	-0.2971
d3	0.1404	0.015	0.111	0.1698
d4	0.7328	0.0798	0.5764	0.8893
d5	-0.00386	0.000244	-0.00433	-0.00338
d6	-0.7646	0.2531	-1.261	-0.2682

CL = 95 % confidence limits.

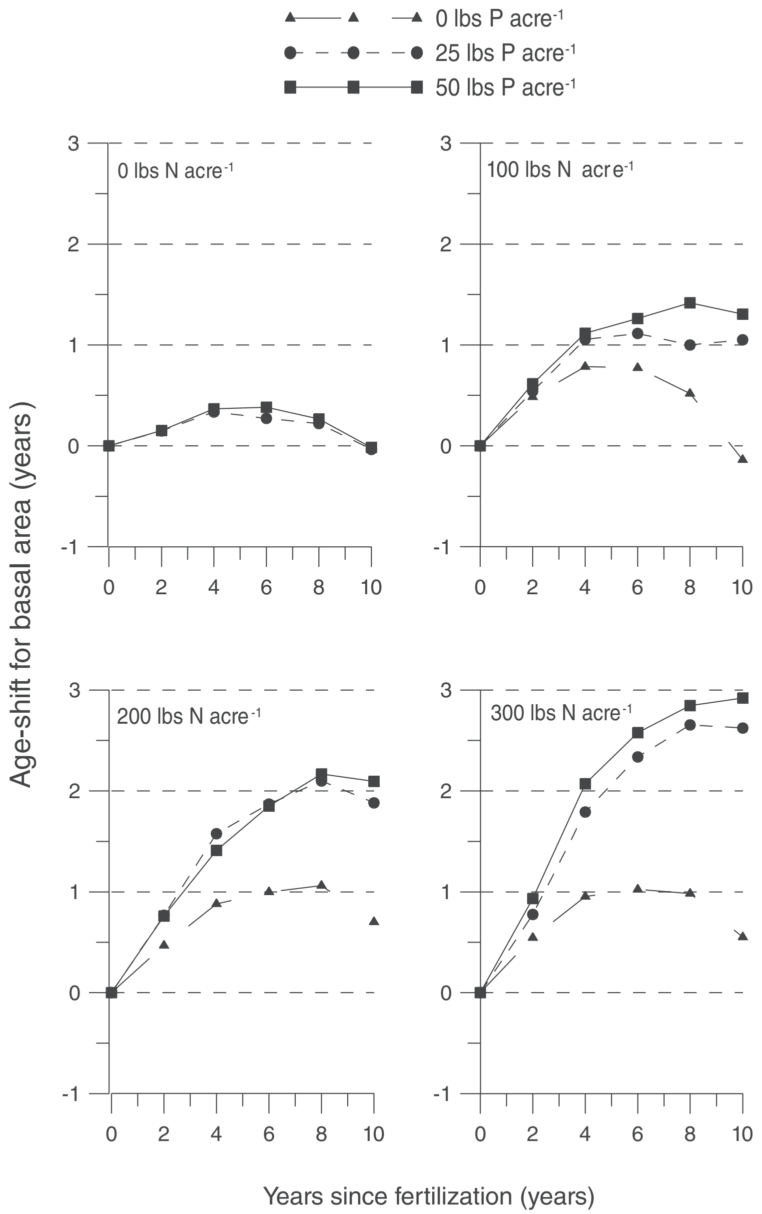

Figure 1—Age-shifts determined for basal area from the Regionwide 13 data. The four graphs show the age-shifts for 0, 100, 200, and 300 pounds/acre N respectively and on each graph the age-shift resulting from 0, 25, and 50 pounds/acre P added with the respective N application is given.

incorporated into existing regional and company-specific growth and yield models indicates a degree of transferability in the technique that makes it attractive. Further work should focus on incorporating site-specific factors such as leaf area and growth efficiency, rather than stand specific parameters (e.g., age and stocking) into the model. In addition, future work needs to identify differences in response due to age-shifts, as opposed to changes in site quality which will allow distinction between Type B and A responses.

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