ESTIMATING ANNUAL GROWTH LOSSES FROM DROUGHT IN LOBLOLLY PINE PLANTATIONS

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Abstract—Growth data over the past 10 years from loblolly pine (*Pinus taeda* L.) plantations established across the natural range of the species were linked with annual rainfall data over the same period to evaluate the impact of drought on stand growth. Regression procedures were used to determine (1) whether dominant height growth or basal area growth or perhaps both were correlated with local rainfall, (2) whether annual rainfall was a significant predictor of annual growth in the presence of other stand and site variables, and (3) whether prediction equations could be developed that would provide reasonable estimates of growth loss during periods of drought. Results show that basal area growth but not dominant height growth is correlated with rainfall for these data. A prediction equation was developed that can be used to estimate the effect of rainfall on annual basal area growth. The equation should be useful for forest managers needing to estimate basal area and volume growth losses due to drought conditions in loblolly pine plantations.

INTRODUCTION

It has long been known that the amount and distribution of annual precipitation affects tree growth. In one of the earliest studies relating precipitation to the growth of pine (*Pinus* spp.) in the South, Coile (1936) demonstrated graphically the correlation of diameter growth of four southern pine species with annual rainfall. Bassett (1964) used tree growth and daily precipitation data acquired at the Crossett Experimental Forest in southeast Arkansas to correlate seasonal growth with rainfall. He divided the growing season into "growth days" and "no-growth" days, based on rainfall and potential evaporation, and developed a growth index to quantify the relationship of basal area and volume growth to precipitation. Langdon and Trousdell (1979) examined these data further and found large differences in annual basal area and volume growth between years characterized by a dearth and glut of precipitation. Jacobi and Tainter (1988) used the methods of dendrochronology to evaluate annual ring growth in loblolly pine (*P. taeda* L.) stressed by drought on the Piedmont of South Carolina. They found significant annual loss of radial growth in loblolly pine stands during periodic drought years from the 1950s through the severe drought of 1980. Both Wheeler and others (1982) and Yeiser and Burnett (1982) documented the loss of volume growth and mortality during the severe drought of August 1979 through December 1980 in Arkansas.

While the importance of precipitation on loblolly pine growth is well known and documented, most growth-and-yield models do not explicitly account for the effects of precipitation. The major reasons for this are: (1) total precipitation across the loblolly range varies widely both spatially and temporally making it difficult to estimate precipitation at any given site for any given year and (2) the distribution through the year of the total precipitation will have an effect on tree growth and is also difficult to predict.

Given these obstacles, developers of growth-and-yield models have generally assumed that the variation in growth associated with precipitation averages out over the rotation toward some mean effect that is confounded with other site factors and included in the overall site index value for a stand. For long-term projections this may be a reasonable assumption. However, when short-term projections are needed for inventory updating or immediate planning for wood supply, the variation in precipitation can result in over- or underprediction of volume yields, especially during seasons of unusual drought.

The purpose of this study was to evaluate the impact of annual precipitation on the growth of loblolly pine plantations across the region and develop a model that can be used to adjust growth-and-yield estimates for losses due to drought.

DATA

Dominant height and basal area measurements from permanent plots established in 3- to 8-year-old intensively managed loblolly pine plantations (IMP) across the natural loblolly pine growing region in the Piedmont, Atlantic, and Gulf Coastal Plain areas (fig. 1) were used for this study (Amateis and others 2006). The plots were installed during the period 1996 to 2000 in plantations representative of current loblolly pine plantation management and silvicultural practices. All received site preparation and vegetation control treatments appropriate for the site, were planted with genetically improved stock suitable for the locale, and have received operationally applied fertilization and competition control treatments as needed. Mostly unthinned plots of 0.15-acre size were used for this study, although there were some thinned plots as well. Each plot was measured at establishment and subsequently on a 1-, 2-, or 3-year cycle. Estimates of average annual dominant height and basal area growth between measurements were obtained by differencing successive measurements and dividing by the number of years between measurements (linear interpolation). There was a total of 1,276 annual dominant height and basal area growth measurements for ages 5 to 15 (table 1).

Interpolated annual precipitation estimates occurring at each IMP site for the period 1997 to 2006 were obtained from the PRISM climate database (http://www.prismclimate.org).

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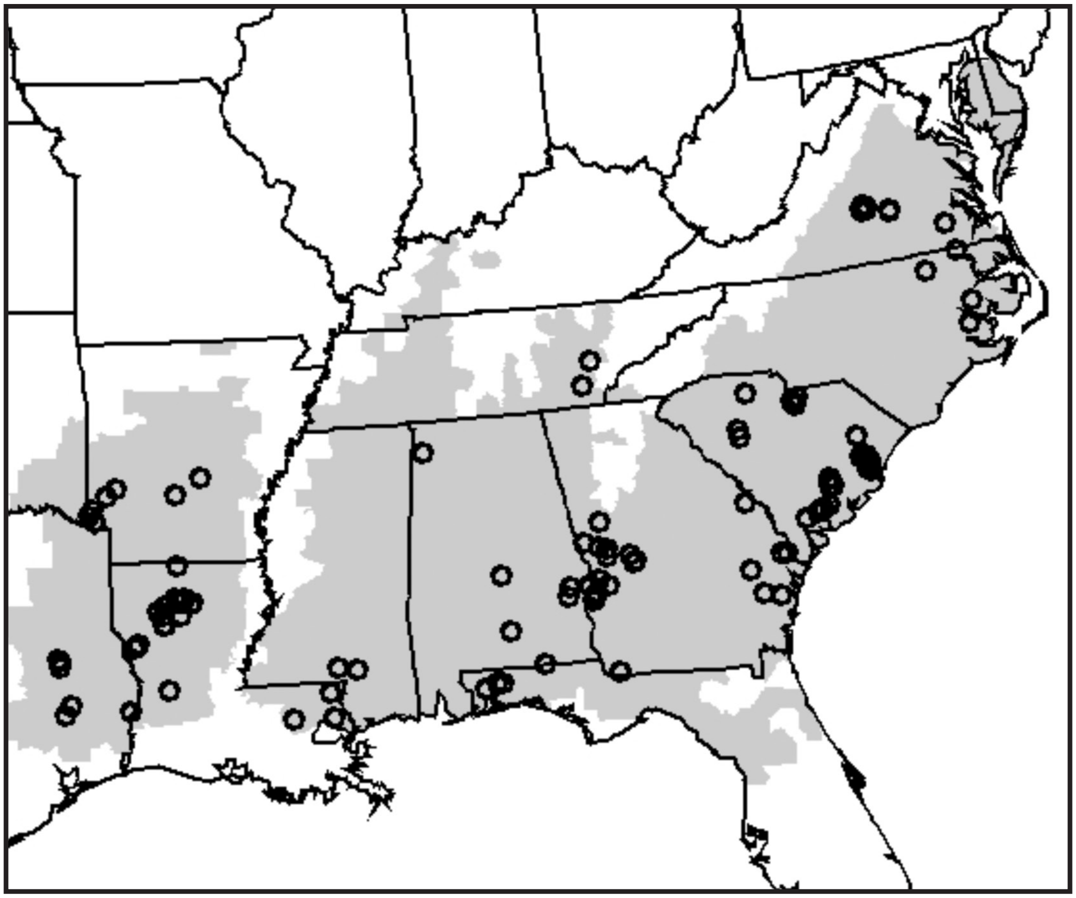

Figure 1—Plot locations for intensively managed loblolly pine plantations study (grey area indicates the natural range of loblolly pine).

Table 1—Summary statistics for 1,276 dominant height and basal area growth observations

Variable	Mean	Std. dev.	Minimum	Maximum
Age (years)	8.5	2.4	5.0	15.0
Site index (feet), base 25	71.4	7.3	51.6	94.3
Basal area (square feet per acre)	74.2	35.7	1.0	183.9
Dominant height (feet)	29.4	9.9	4.9	59.9
Basal area growth (square feet per acre per year)	13.2	4.5	1.0	28.2
Dominant height growth (feet per year)	3.6	1.0	0.6	10.5
Annual precipitation (inches)	51.4	8.7	34.5	73.1
Latitude (decimal degrees)	33.2	2.0	30.4	37.5
Longitude (negative decimal degrees)	–85.9	6.1	–95.0	–76.9

Std. dev. = standard deviation.

An average annual precipitation estimate for each growth period on each plot was computed by summing the annual precipitation estimates between measurements and dividing by the number of years between measurements. These annual precipitation estimates were merged with the annual growth data for the same year to construct a dataset that could be used to evaluate the impact of precipitation on loblolly pine growth.

METHODS AND RESULTS

The approach taken for this study was to use regression methods to develop baseline prediction equations for estimating annual dominant height (G_{HD}) growth (feet per year) and basal area (G_{BA}) growth (square feet per acre per year) from stand and site variables typically used in growth-and-yield models. Then, annual precipitation was added to the base model to determine if precipitation was a significant regressor in the presence of the other variables.

A power function was used as a base model and linearized for both G_{HD} and G_{BA}:

$$\ln(G_{HD}) = b_0 + b_1 \ln(1/A) + b_2 \ln(HD) + b_3 \ln(S) \quad (1)$$

$$\ln(G_{BA}) = b_0 + b_1 \ln(S) + b_2 \ln(HD) + b_3 \ln(BA) + b_4 \ln(LAT) \quad (2)$$

where

A = stand age
HD = average height of dominant and codominant trees
S = site index (feet, base 25)
BA = basal area (square feet per acre)
LAT = latitude (decimal degrees)

Other stand and site variables including number of trees, longitude, and physiographic region were not significant regressors in either equation (1) or (2) and did not reduce the PRESS statistic. Base equations (1) and (2) have *r*-square values of 0.42 and 0.50, respectively.

The logarithm of annual precipitation (PPT) was added as a regressor to both base models, and the models were refitted to the data. For equation (1), PPT was not a significant regressor. For equation (2), however, PPT was significant and adding it to equation (2) to create equation (3) resulted in an *r*-square of 0.53, a reduction of the PRESS statistic and a reduction in the mean square error by about 7 percent over equation (2).

$$\ln(G_{BA}) = b_0 + b_1 \ln(S) + b_2 \ln(HD) + b_3 \ln(BA) + b_4 \ln(LAT) + b_5 \ln(PPT) \quad (3)$$

Attempts to improve equation (3) by adding additional regressor variables including the lagged precipitation value from the previous year were unsuccessful. Interaction terms were also not significant regressors. Table 2 presents the fit statistics and parameter estimates for equations (2) and (3).

DISCUSSION

An important result of this study was that annual precipitation was not correlated with dominant height growth for these data. This may be due to the fact that much of the annual height growth occurs relatively early in the growing season drawing on moisture that has accumulated during the previous dormant season. Drought conditions that might negatively impact height growth generally do not materialize until later in the growing season. Physiologically, trees will favor height growth over cambial growth when under stress which may be another reason annual rainfall is not significant.

Basal area growth, on the other hand, was significantly correlated with local annual precipitation. This may be because considerable cambial growth occurs later in the growing season when drought conditions are likely to be more severe. It may also be because, as noted above, trees will utilize resources to favor height growth at the expense of diameter growth when under stress.

Table 2—Basal area growth prediction equation fitted to stand and site variables without [equation (2)] and with [equation (3)] annual precipitation included

	Base model [equation (2)]			Base model with precipitation [equation (3)]		
Parameter	Estimate	Standard error	*P*-value	Estimate	Standard error	*P*-value
Intercept	–2.8769	0.5723	<0.0001	–6.914	0.6933	<0.0001
ln(S)	1.4405	0.0815	<0.0001	1.473	0.0787	<0.0001
ln(HD)	–1.2885	0.0383	<0.0001	–1.337	0.0373	<0.0001
ln(BA)	0.4682	0.0221	<0.0001	0.4889	0.0214	<0.0001
ln(LAT)	0.4516	0.1259	<0.0003	1.072	0.1375	<0.0001
ln(PPT)				0.4592	0.0476	<0.0001
	MSE = 0.0704 R^2 = 0.50			MSE = 0.0656 R^2 = 0.53		

S = site index (feet, base 25); HD = average height of dominant and codominant trees (feet); BA = basal area (square feet per acre); LAT = latitude (decimal degrees); PPT = annual precipitation (inches); MSE = mean square error.

Equation (3) can be used in various ways to estimate the impact of losses due to drought on the growth of loblolly pine plantations. One way is to use a growth-and-yield model to make a 1-year projection from observed stand and site conditions. This will result in an estimated basal area and volume for "normal" (or "average") levels of precipitation. Then, model 3 can be implemented and estimated annual basal area growth under different levels of precipitation can be compared to the "normal" level estimated using the growth-and-yield model.

Equation (3) can also be used directly to adjust output from growth-and-yield models by an appropriate percentage. For example, in 2007 parts of Alabama experienced a severe drought where precipitation for the year was about 26 inches instead of the "normal" 56 inches. For a stand at latitude 34° with site index 65 feet, dominant height of 50 feet, and basal area of 150 square feet per acre, equation (3) predicts basal area growth of about 8 square feet per acre per year under "normal" precipitation and 5.6 square feet per acre per year under drought conditions. This suggests a basal area growth loss for the year of about 30 percent. Since height growth will not be much affected by drought, and assuming the form factor for trees growing under drought conditions as compared to trees growing under conditions of "normal" precipitation will not be much affected either, volume growth loss for the year would be expected to be about 30 percent as well.

ACKNOWLEDGMENTS

The support of the Loblolly Pine Growth and Yield Research Cooperative at Virginia Tech is gratefully acknowledged.

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