1992

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W. D. Hacker
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University

M. Victor Bilan
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University

Repository Citation

Hacker, W. D. and Bilan, M. Victor, "Site Factors Affecting Growth of Loblolly Pine in the Post Oak Belt" (1992). *Faculty Publications*. 371.
https://scholarworks.sfasu.edu/forestry/371

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Site Factors Affecting Growth of Loblolly Pine in the Post Oak Belt

W. David Hacker *and* **M. Victor Bilan,** *School of Forestry, Stephen F. Austin State University, Nacogdoches, TX 75962.*

*ABSTRACT. A study was conducted in the Post Oak Belt of East Texas to determine which site factors affected height growth of loblolly pine (*Pinus taeda *L.). Height/age pairs were developed from stem analysis. Nonlinear regression was implemented to develop generalized height-age model. After curves were developed, stepwise regression was used to determine if an environmental variable impacted height growth. Environmental factors correlated with height growth included* A *horizon depth and those related to moisture relations including seasonal precipitation, average daily temperature, and texture of the* A *horizon.*

South. J. Appl. For. 16(4):197–200

The Post Oak Belt of East Texas lies to the west of the natural range of southern pines (LBJ School of Public Affairs 1978). Although a number of pine plantations, more than 300, have been established throughout the area, there are few evaluation data available. The work by Sternitzke (1967) suggested that the 11 eastern-most counties from the Post Oak Belt have the best potential for pine plantation establishment. Sanders (1980) reported that pine conversion was successful on mesic sites, but on sites with low moisture regimes, pine plantation establishment failed. Survival of southern pines was found to be quite good north of the Navasota River (Hansen 1986). Use of plant indicators has been suggested to determine where pine could be successfully grown in this zone (Silker 1963).

Studies conducted in the controlled environment of the greenhouse have shown that loblolly pine (*Pinus taeda* L.) and shortleaf pine (*P. echinata* Mill.) survived almost as well on soils from the Post Oak Belt as on soils from the Pineywoods (Bilan and Stransky 1966). Average temperature as well as frequency and intensity of precipitation during the summer months were found to be significant factors in limiting loblolly pine to its present range (Hocker 1956). Hansen (1986) attempted to quantify survival and growth of all four species of commercial southern pine growing in the Post Oak Belt north of the Navasota River. He found the most critical factor in establishing southern pine plantations appeared to be the initial survival of planted seedlings. Once seedlings had survived the first 3 to 5 years, growth was found to be comparable to sites in the pine-mixed hardwood forest to the east. Site index curves developed by Hacker and Bilan (1991) indicated favorable height growth patterns for loblolly and slash pine (*P. elliottii* Engelm.).

There are no long-term data available to document which environmental factors are most critical for successful height growth of loblolly pine in the Post Oak Belt. The objectives of this study are to develop a generalized height growth model of loblolly pine and to determine the site variables that may affect height growth.

THE DATA

Thirty-two old-field loblolly pine plantations in the Post Oak Belt of East Texas were evaluated. Sampling was conducted by approximating the center of each plantation and felling from one to three dominant or codominant trees per plantation. Sample points were carefully chosen to avoid the influence of soil erosion, fungal disease, or damage by insects, fire, or ice.

Examination of individual trees was conducted by felling sample trees and then delimbing each up to the terminal leader. Cross-sectional cuts were then made at 24-in. intervals, and the rings at the stump and at the top of each bolt were counted and recorded. Plantations ranged in age from 12 to 46 yr with heights ranging from 23 ft to 99 ft (Table 1). The 89 stem-analysis trees from the 32 plantations yielded 2683 height-age pairs. True heights were estimated using the adjustment recommended by Carmean (1972).

Soil samples were obtained from

Note: This study was funded in part by McIntire-Stennis funds. W. David Hacker's present address: Uplands Research Lab, Great Smoky Mountains National Park, Rt. 2, Box 260, Gatlinburg, TN 37738.

Table 1. Distribution of loblolly pine plantations by age and height.

	Height								
Age	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	TOTAL
10–19	1	2	6						9
20–29				3	8	3	1		15
30–39				1	2	3		1	7
40–49								1	1
TOTAL	1	2	6	4	10	6	1	2	32

each plantation. Samples were taken in close proximity to the fallen trees with the aid of a bucket auger. Thicknesses of the strata of the organic layer and each soil horizon were recorded to a depth of 60 in. One sample was taken from the uppermost 6 in. of the soil and another from a depth of 20 in. below the top of the *B* horizon. If the *B* horizon was less than 20 in. in thickness, the second sample was obtained from the center of the *B* horizon. Mechanical analysis of the soil samples was conducted according to the method prescribed by Bouyoucos (1951, 1962).

Weather data were obtained from the nearest weather station to a given plantation. Average daily temperature and seasonal precipitation were calculated. Because of the wide variation in amount and duration of precipitation in convective thunderstorms, it was difficult to make an inference regarding the effects of precipitation on growth, however, abnormally dry or wet periods can be segregated from typical periods. The length of the growing season (frost-free days) was also noted.

MODEL DEVELOPMENT

For developing height growth models of southern pines based on age, the most commonly used methods are the regression technique recommended by Schumacher (1939) and the Chapman-Richards function (Chapman 1961, Richards 1959). The suitability of both approaches was evaluated. A line first was fitted to the data using the regression technique recommended by Schumacher resulting in an r^2 of 0.6674. A plot of the residuals over age showed deviations from normality; hence this method was discarded in favor of the Chapman-Richards function. The Chapman-Richards function yielded the following equation:

$$H = 99.147 * [1.0 - \mathrm{EXP}(0.057 * A)]^{1.560}$$

where

H = average total height (ft)
A = age (yr).

Height over age was plotted by using this equation to produce a generalized height growth curve for the Post Oak Belt. The resultant nonlinear function explained 90.78% of the variation.

After the development of a height growth model, environmental variables were evaluated by means of stepwise regression with observed plantation heights as the dependent variables. Environmental factors used as independent variables included: growing season length, average season rainfall (in. of precipitation) for March–May, June–August, September–November, and December–February, average daily temperature (degrees Fahrenheit) for March–May, June–August, September–November, and December–February; depth of the *A* horizon, pH of the *A* horizon, percent clay and silt of the *A* horizon, thickness of the *B* horizon, pH of the *B* horizon, and percent clay and silt of the *B* horizon. Variables were considered significant if $P < 0.05$.

RESULTS

Five-year increments through 50 years were selected for evaluation of the effects of environmental variables on height growth. Independent variables that proved to be statistically significant with percent variation explained are shown in Table 2.

Age 5. The predicted height of loblolly pine from the Chapman-Richards model was 11 ft. Winter precipitation (RDECFEB) had the greatest impact on height growth at this young age. Winter precipitation accounted for 29% of the variation in height and was positively correlated with height. Spring rain (RMARMAY) accounted for an additional 10% of the variation in height growth and was negatively correlated with height. The resulting equation ac-

Table 2. Regression equations on selected loblolly pine ages.

Age class (yr)	Equations (percent variation explained)	R^2	P-Value
5	H = 8.6471 + 0.7011 (RDECFEB) − 0.3767 (RMARMAY) (29) (10)	0.39	0.0009
10	H = 126.8097 − 1.221 (TJUNEAUG) (18)	0.18	0.0160
15	H = 38.4355 + 0.0926 (ADEPTH) (14)	0.14	0.0426
20	H = 2.1036 + 2.418 (RMARMAY) + 0.1281 (ADEPTH) (21) (13) 1.3644 (RSEPTNOV) (13)	0.47	0.0006
25	H = 21.2166 + 3.047 (RMARMAY) + 3.22401 (29) (12) (RDECFEB) + 1.3026 (RSEPTNOV) (7)	0.48	0.0003
30	H = 516.6382 − 5.5302 (TJUNEAUG) (28)	0.28	0.0021
35	H = 636.4452 − 6.9457 (TJUNEAUG) (32)	0.32	0.0010
40	H = 732.6018 − 8.0845 (TJUNEAUG) (32)	0.32	0.0009
45	H = 812.6002 − 9.0368 (TJUNEAUG)	0.32	0.0010
50	H = 869.4398 − 9.7106 (TJUNEAUG) (30)	0.30	0.0013

counted for 39% of the variation in height growth at age five (P = 0.0009).

Age 10. The predicted height of loblolly pine from the Chapman-Richards model was 27 ft. Summer temperature (TJUNEAUG) was the only environmental variable that significantly affected height growth. Summer temperature was negatively correlated with height growth and accounted for 18% of the variation (P = 0.0160).

Age 15. The predicted height of loblolly pine from the Chapman-Richards model was 41 ft. The depth of the *A* horizon was the only variable to significantly influence height growth at this age. The depth of the *A* horizon (ADEPTH) accounted for 14% of the variation in height (P = 0.0426). This variable was positively correlated with height growth at age 15.

Age 20. The predicted height of loblolly pine from the Chapman-Richards model was 54 ft. The greatest amount of variation in loblolly pine height came from spring rainfall. Spring rain (RMARMAY) accounted for 21% of the total variation. The depth of the *A* horizon (ADEPTH) accounted for 13% of the variation in height. Fall precipitation (RSEPTNOV) contributed 13% of the variation of height. All three of these variables were positively correlated with height growth. The equation accounted for a total of 47% of the variation in tree height at age 20 (P = 0.0006).

Age 25. The predicted height of loblolly pine from the Chapman-Richards model was 65 ft. Spring rain (RMARMAY) accounted for 29% of the total variation in height growth. Winter precipitation (RDECFEB) accounted for another 12% of the variation in height. Autumn rainfall (RSEPTNOV) accounted for 7% more of the variation in height growth. These three variables were positively correlated with height growth. This regression accounted for 48% of the variation in height growth of loblolly pine at age 25 (P = 0.0003).

Age 30. The predicted height of loblolly pine from the Chapman-Richards was 73 ft. Summer average daily temperature (TJUNEAUG) accounted for 28% of the variation in height growth (P = 0.0021). Summer average daily temperature was negatively correlated with height growth at this age.

Age 35. The predicted height of loblolly pine from the Chapman-Richards model was 79 ft. Summer average daily temperature (TJUNEAUG) accounted for 32% of the variation in height growth for 35-year-old loblolly pine (P = 0.0010) and was negatively correlated to height growth. Summer average daily temperature was the only environmental variable that was statistically significant.

Age 40. The predicted height of loblolly pine from the Chapman-Richards model was 84 ft. The only environmental variable significantly affecting height growth was summer average daily temperature (TJUNEAUG). This negatively correlated variable accounted for 32% of the variation in height growth at age 40 (P = 0.0009).

Age 45. The predicted height of loblolly pine from the Chapman-Richards model was 88 ft. Summer average daily temperature (TJUNEAUG) was the only variable significantly affecting height growth. Summer average daily temperature accounted for 32% of the variation in height growth and was negatively correlated (P = 0.0010).

Age 50. The predicted height of loblolly pine from the Chapman-Richards model was 90 ft. The only variable that significantly affected height growth at this age was summer average daily temperature (TJUNEAUG). Average daily temperature in the summer was negatively correlated with height growth at age 50. This regression accounted for 30% of the variation of height growth of loblolly pine at an age of 50 years (P = 0.0013).

DISCUSSION

Environmental variables associated with moisture relations appeared to be the limiting factors throughout the life of loblolly pine growing in the Post Oak Belt.

Seasonal rainfall appeared most prominant in stepwise regression equations through age 25. Since the Post Oak Belt is an area given to frequent and sometimes severe droughts, one would expect rainfall to limit growth, especially on younger trees with their smaller root systems, and this was what was observed in this study. Loblolly pine height growth was positively correlated with depth of the *A* horizon at ages 15 and 20. The *A* horizon is where most of the nutrients are found in the soil. Trees have smaller root systems when they are young and by the time they get older the root systems become better developed and grow beyond the *A* horizon if it is shallow, so it is not surprising that *A* horizon depth affects height growth at these intermediate ages.

At ages of 30 years and up, summer average daily temperature was inversely correlated with height growth. This is exactly what is expected, because the higher the temperature, the higher the potential evapotranspiration. As trees mature they have more fully developed root systems making the variables that are significant at younger ages less important. Mature trees also have larger crowns and greater leaf areas, hence there is greater evapotranspiration and high temperatures would only aggravate the situation. Indeed, as the trees got older and larger, it was observed that the regression coefficient associated with summer average daily temperature became more negative.

Besides determining what site factors may affect loblolly pine growth, this study supports claims that many sites within the Post Oak Belt are suitable for pine conversion. Growing pine in this region may be a viable land-use alternative especially with the increased demand for forest products facing the nation. ☐

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The Potential Economic Effect of Lease Hunting on Forest Management in the Southeast

Allan P. Marsinko, *Department of Forest Resources, Clemson University, Clemson, SC 29634;* **Webb M. Smathers, Jr.,** *Department of Agricultural and Applied Economics, Clemson University, Clemson, SC 29634;* **David C. Guynn, Jr.** *and* **Gerald L. Stuckey, Jr.,** *Department of Forest Resources, Clemson University, Clemson, SC 29634.*

ABSTRACT. A survey was conducted of 1989 forest industry hunt lease programs in the southern United States. Average annual lease fees were $2.15/ac and respondents placed additional implicit values of $2.15/ac and $3.11/ac respectively for public relations and protection (access control, property damage, etc.) benefits. Contributions to net present value ranged from $22.37 for a conservative estimate of leasing alone to $96.64 for an estimate of all benefits when discounted at 6% over a 25-yr rotation. Interest in leasing by industry has increased since a similar survey was conducted in 1985.

South. J. Appl. For. 16(4):200–203

Forest industry hunt-lease programs are becoming more prevalent in the United States as opportunities for quality hunting experiences decrease and the benefits of such programs become apparent to hunters and landowners. Busch and Guynn (1988) described the status of forest industry hunt-lease programs in the southern United States in 1984 based on a survey conducted in 1985. They found average lease fees to be in the $1.25–2.00/ac range, and they found that respondents considered such nonmonetary benefits as public relations, access control, and reduced property damage to be "important" or "very important." Average costs of leasing were determined to be $0.82/ac.

We repeated Busch and Guynn's survey in 1990 with increased emphasis on costs and benefits. Our survey attempted to estimate the value of the benefits in dollars by relating them to lease fees. Data were collected for the previous year (1989). This paper discusses the value of leasing and its potential economic effect on forest management based on an analysis of the benefits and costs.

METHODS

The survey was based in part on Busch and Guynn's 1985 survey, which used Dillman's (1978) model. A questionnaire was mailed to a specifically targeted group of wildlife managers employed by forest industries in the southern United States. Each potential respondent was identified by name via telephone calls to firms believed to be involved with forest management and lease hunting. At this time, the objectives of the study were explained, and assistance of potential respondents was solicited. Busch and Guynn's original mailing list was updated and enhanced by information from Clephane and Carroll (1980) and Moody's Industrials (Moody's Investors Service 1987). Initially, 104 firms were identified, of which 89 were surveyed. Effects of general economic conditions within the forest industry became apparent in that several firms had gone out of business and several others had been taken over. The study was based on a mail survey with a followup letter and a second letter and survey to nonrespondents. Although the survey was relatively long and time-consuming, interest among wildlife managers was high, resulting in a response rate of 70%. Of those who returned the survey, 10 did not lease lands for hunting and 2 did not fill out the