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ABSTRACT. *A study was conducted in the Post Oak Belt of East Texas to determine which site factors affected height growth of slash pine* (Pinus elliottii *Engelm.). Height–age pairs were developed from stem analysis data. Nonlinear regression was implemented to develop a generalized height–age model. After curves were developed, stepwise regression was used to determine impacts of environmental variables on 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. 21(2):71–74.*

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 pine plantations have been established throughout the area, there are few evaluation data available. This is especially true for slash pine (*Pinus ellottii* Engelm.). Hansen and Bilan (1989) quantified survival and growth of slash pine growing in the Post Oak Belt north of the Navasota River They found the most critical factor in establishing pine plantations to be the initial survival of planted seedlings. After establishment, growth was comparable to those on sites in the pine-mixed hardwood forests to the east. Site index curves developed by Hacker and Bilan (1991) indicated favorable height growth patterns for slash pine. There are no long-term data available indicating which environmental factors are most critical for successful height growth of slash pine in the Post Oak Belt. The objectives of this study were to develop a generalized height growth model for slash pine and to determine the site variables that may affect height growth.

The Data

Eighteen old-field slash 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 1 to 4 dominant or codominant trees per plantation. Only 1 tree per plantation was sampled in some cases because of restrictions placed by landowners. 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 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 14 to 45 yr with heights ranging from 27 ft to 97 ft (Table 1). The data from 18 plantations yielded 1,511 height–age pairs from 49 trees. True heights were estimated using the adjustment recommended by Carmean (1972).

Soil samples were obtained from each plantation in close proximity to the fallen trees. Thickness of the strata of the organic layer and each soil horizon was 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 to determine soil texture was conducted according to the method prescribed by Bouyoucos (1951, 1962). Soil pH was determined using a glass electrode pH meter.

Weather data were obtained from the nearest weather station to each 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.

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Table 1 Distribution of slash pine plantations by age and height (number of trees sampled)

	Height (ft)								
Age (yr)	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	Total
10–19	1 (3)	1 (3)	3 (10)						5
20–29				1 (3)	2 (6)	7 (17)			10
30–39								1 (3)	1
40–49							1 (1)	1 (3)	2
Total	1	1	3	1	2	7	1	2	18

Model Development

Using the Chapman-Richards function (Richards 1959, Chapman 1961), a height growth curve based on plantation age was developed yielding the following equation:

$$H = 98.221 * [1.0\text{-EXP}(-0.063*A)]^{1.603}$$

where

H = Average total height (ft)

A = Age (yr)

Height over age was calculated by using this equation to produce a generalized height growth curve for the Post Oak Belt. The resultant nonlinear function explained 94.61% 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.

Results

Five-year increments through 50 yr 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 slash pine from the Chapman-Richards model was 12 ft. Autumn rainfall (RSEPTNOV) had the greatest impact on height growth at this young age. Fall precipitation accounted for 20% of the variation in height and was positively correlated with height. Spring rain (RMARMAY) accounted for an additional 11% of the variation in height growth and was negatively correlated with height. Percent clay and silt in the A horizon (ACLAYSIL) was negatively correlated and accounted for 8% of the variation. The resulting equation accounted for 39% of the variation in height growth at age 5 (P = 0.0798).

Age 10

The predicted height of slash pine from the Chapman-Richards model was 29 ft. Spring precipitation (RMARMAY) accounted for 33% of the variation in height growth. Depth of the A horizon (ADEPTH) accounted for 13% of height growth variation. This equation accounted for 46% of the variation in slash pine height growth at age 10 (P = 0.0131)

Age 15

The predicted height of slash pine from the Chapman-Richards model was 45 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 = 0.1421). 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 58 ft. The depth of the A horizon (ADEPTH) accounted for 33% of the variation in height and was positively correlated (P = 0.0155).

Age 25

The predicted height of slash pine from the Chapman-Richards model was 68 ft. Mean daily temperature in the summer had the greatest effect on slash pine height growth at this age. Summer temperature (TJUNEAUG) accounted for 46% of the variation of slash pine height growth. Summer rainfall (RJUNEAUG) contributed another 16% of the variation. Both of these were negatively correlated with height growth at an age of 25 yr. This regression accounted for 62% of the variation in height growth of loblolly pine at age 25 (P = 0.0027).

Age 30

The predicted height of slash pine from the Chapman-Richards model was 75 ft. Summer average daily temperature (TJUNEAUG) accounted for 52% of the variation in height growth. Summer rainfall (RJUNEAUG) accounted for another 15% of variation. Summer average daily temperature and summer rainfall were negatively correlated with height growth at this age and together accounted for 67% of the variation in height growth (P = 0.0004).

Table 2 Regression equations to predict height from site variables on selected slash pine ages *

Age Class (yr)	Equations (percent variation explained)	R^2	P-value
5	H = 10.4224 – 1.2397(RMARMAY) (11) + 1.5628(RSEPTNOV) (20) –0.1090(ACLAYSIL) (8)	0.39	0.0798
10	H = 16.1561+2.7209(RMARMAY) (33) +0.1122(ADEPTH) (13)	0.46	0.0131
15	H = 40.2230+0.0898(ADEPTH) (14)	0.14	0.1421
20	H = 20.4319+2.7153(RMARMAY) (33)	0.33	0.0155
25	H = 550.8361 – 5.5328(TJUNEAUG) (46) – 4.1867(RJUNEAUG) (16)	0.62	0.0027
30	H = 678.7964 – 6.9545(TJUNEAUG) (52) – 4.9720(RJUNEAUG) (15)	0.67	0.0004
35	H = 789.3483 – 8.1552(TJUNEAUG) (54) – 5.9004(RJUNEAUG) (17)	0.71	0.0002
40	H = 866.4173 – 9.0352(TJUNEAUG) (55) – 6.1813(RJUNEAUG) (15)	0.70	0.0002
45	H = 942.3117 – 9.8759(TJUNEAUG) (57) – 6.7174(RJUNEAUG) (15)	0.72	0.0001
50	H = 980.8625 – 11.0554(TJUNEAUG) (63)	0.63	0.0001

* Definitions of acronyms are in Appendix 1.

Age 35

The predicted height of slash pine from the Chapman-Richards model was 81 ft. Summer average daily temperature (TJUNEAUG) accounted for 54% of the variation in height growth for 35 yr old slash pine. Summer rainfall (RJUNEAUG) accounted for 17% more variation. These variables were negatively correlated to height growth and accounted for 71% of the variation in height growth (P = 0 0002).

Age 40

The predicted height of slash pine from the Chapman-Richards model was 86 ft. Summer average daily temperature (TJUNEAUG) was responsible for 55% of the variation in height growth at age 40. Summer rainfall (RJUNEAUG) contributed another 15% to the variation in height growth of slash pine. These variables were negatively correlated with height growth and accounted for 70% of the variation at age 40 (P = 0.0002).

Age 45

The predicted height of slash pine from the Chapman-Richards model was 89 ft. Summer average daily temperature (TJUNEAUG) accounted for 57% of the variation in height growth for 45 yr old slash pine. Summer precipitation (RJUNEAUG) accounted for 15% in variation. These negatively correlated variables accounted for 72% of the variation in height growth (P = 0.0001).

Age 50

The predicted height of slash 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), which was negatively correlated with height growth. This regression accounted for 63% of the variation of height growth of loblolly pine at an age of 50 yr (P = 0.0001).

Discussion

Environmental variables associated with moisture relations and the A horizon depth appeared to be the only limiting factors affecting slash pine growing in the Post Oak Belt. This is expected because the A horizon is the area with the highest biological activity. Seasonal rainfall variables are contained in all but 1 of the equations through age 45. Spring rainfall appears to be very important at an early age. As trees mature, summer rainfall becomes more important. At ages 25 through 45 yr it is observed that summer rainfall was inversely correlated with height growth. This seemed counter-intuitive since height growth should have increased with rainfall. However, this is consistent with the findings of Shoulders and Tiarks (1980) in studies in Louisiana and Mississippi where slash pine is exotic. In their study, slash pine height growth was reduced (the slope of the height growth curve changed from positive to negative) when rainfall exceeded

144 cm (approx. 57 in.) annually. Jackson (1962) found similar results in his study of slash pine. He concluded that high rainfall during the growing season led to reduced root aeration.

At ages 25 yr 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 evapotranspiration is exacerbated by high temperatures. In addition to identifying site factors affecting slash pine growth, this study supports claims that many sites within the Post Oak Belt are suitable for pine conversion. However, the data indicate that slash pine should be used only in short rotation silviculture because of reduced height growth observed after an age of 30 yr.

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Appendix 1. Glossary of acronyms.

ACLAYSIL	percent clay and silt in the A horizon
ADEPTH	depth of the A horizon
RMARMAY	total precipitation, March through May
RJUNEAUG	total precipitation, June through August
RSEPTNOV	total precipitation, September through November
TJUNEAUG	average daily temperature, June through August