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Thermal Efficiency: A Possible Determinant of Height Growth Potential in *Young* Loblolly *Pines*

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Abstract. Height growth of 10 loblolly pines (*Pinus taeda* L.) during one growing season ranged from 35.7 to 126.9 cm. Ninety-four percent of these tree-to-tree differences in height growth were accounted for by two thermal characteristics of each tree: (1) threshold temperature for growth and (2) growth rate per unit of heat above 40°F (4.4°C). These parameters were derived from the nocturnal growth of the first flush of three shoots per tree measured in late April and early May. Threshold temperature alone accounted for 62 percent of the differences in height growth. Growth rate alone had no significant effect. The parameters were more closely related to terminal shoot growth after the first flush ($R^2 = 0.80$) than to first flush lengths alone ($R^2 = 0.66$). Threshold temperatures ranged from 32.3°F (0.2°C) to 43.2°F (6.2°C) and averaged 38.5°F (3.6°C). *Forest Sci. 22:279–282.*

Additional key words. *Pinus taeda,* temperature, heat units, selection, plant growth.

THE GROWTH of 3 shoots on each of 10 loblolly pines (*Pinus taeda* L.) was monitored throughout the 1967 growing season. Earlier, I reported that growth rates of these trees were closely related to air temperatures, especially at night in the absence of daytime stress conditions (Boyer 1970). The purpose of the present study is to explore further the possibility that an individual tree's characteristic responses to temperature have an important bearing on tree-to-tree differences in seasonal height growth.

Methods

The pines were 1.1 to 1.7 m in height, naturally established, and open grown near Durham, North Carolina. Soils of the study area are the eroded phase of White Store sandy loam.

The terminal and two primary lateral buds on each tree were measured on March 4, 1967. The subsequent growth flushes, or phases, of the shoots were measured from the base of the primary bud to the bases of succeeding buds at 2- to 4-day intervals through September 18. The period of active growth for each shoot was considered as the time in which 90 percent of its total growth occurred. Of the remaining 10 percent, half was regarded as having taken place before and half after active growth.

Between April 19 and May 7 growth of the first flush was near its peak. During this time, the thirty shoots were measured twice daily between 8 and 9 a.m. and 4 and 5 p.m. One morning measurement was missed. For each tree the nightly growth (16 hours per day) of all 3 shoots was adjusted to average growth rate, in millimeters per 24 hours. Air temperatures, in degrees F, were recorded by a hygrothermograph that was in a standard weather-instrument shelter located among the study trees. Degree-hour heat sums for each night were obtained by planimetering the area between the temperature trace on the

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hygrothermograph chart and a threshold temperature of 40” F (4.4” C). This temperature was chosen because it was the whole number nearest to the average growth threshold of 39.6” F (4.2” C), that was previously reported for these trees (Boyer 1970).

Since nocturnal growth was more temperature dependent than daytime growth, the thermal response characteristics of each tree were derived by regression exclusively from the data gathered during the 17 nights. The accuracy of each shoot measurement was not better than 1 mm, which was often a substantial fraction of the nightly growth. Averaging the nightly growth of three shoots per tree should have reduced the chance of error. These errors were assumed to be random and contribute to residual error with little effect on regression coefficients.

The model for the regressions was Y = a + *bX* in which Y is average nightly growth rate of 3 shoots, expressed as millimeters per 24 hours, and X is nightly heat accumulation rate per 24 hours, in degree-hours above 40” F. The coefficients represent two thermal response characteristics of each tree. The intercept (a) indicates whether the actual temperature at which the tree begins to grow is above or below the selected base temperature. The slope coefficient (b) indicates growth per degree-hour above the threshold.

The threshold temperature in degrees F for each tree was estimated from the point at which the regression intersected the X axis; the degree-hour value at the point of intersection was converted to degrees from a curve of cumulative change in degree-hour heat sums with change in threshold temperature. The curve was derived from temperature profiles recorded during the 17 nights. The accuracy of each threshold temperature estimate is, however, limited by the errors inherent to the regression from which it was derived.

Once the coefficients and threshold temperatures were determined, regression analyses were used to explore their relationships to: total growth of the first flush, all growth above the first flush, and total seasonal height growth.

TABLE I. Terminal shoot growth* of *the ten study trees.

Tree	17-day measurement period		Season total	
	Nights only	Day and night	First flush	All flushes
	---- millimeters ----			
	70	98	366	764
2	98	152	388	1062
3	21	31	87	357
4	58	93	228	944
5	73	126	334	829
6	87	130	369	911
7	122	16.5	479	1269
8	94	139	321	1107
9	116	186	512	1162
10	92	146	372	1083

Results

Terminal Shoot Growth. Total seasonal growth of the terminal shoots ranged from 357 to 1269 mm (Table 1). Starting dates for shoot growth were between March 28 and April 19, and active growth ceased between July 27 and September 12.

Terminals grew as little as 31 mm and as much as 186 mm during the 17-day period of detailed measurement. About two-thirds of this was nocturnal growth, which ranged from 21 to 122 mm. The lowest temperature during the 17 nights was 32” F (0° C), and the highest was 81° F (27” C); average minimum temperature was 45” F (7” C), and the average maximum was 68” F (20” C) .

Relative Thermal Efficiency. Regressions for all trees were significant at the 0.01 level (Table 2). Threshold temperatures of the trees, estimated from the intercepts, ranged from 32.3° F (0.2” C) to 43.2° F (6.2” C); threshold temperatures averaged 38.5” F (3.6” C) with a standard deviation of 2.9” F (1.8” C). The five trees that had the lowest thresholds were the first to begin growth in the spring and among the last **6** to stop at the end of the season.

TABLE 2. Thermal efficiency parameters for the ten study trees.

Tree	Three sample shoots per tree: Regression coefficients" Intercept	Slope	r^2	Indicated threshold temperature °F	°C
1	0.143	0.0135	0.41	39.5	4.2
2	-0.126	.0230	.77	40.2	4.6
3	-0.898	.0140	.58	43.2	6.2
4	0.515	.0132	.82	38.1	3.4
5	-0.513	.0189	.72	41.3	5.2
6	0.654	.0124	.63	37.5	3.1
7	2.152	.0124	.49	32.3	0.2
8	0.857	.0189	.63	37.8	3.2
9	0.545	.0205	.84	38.7	3.7
10	0.892	.0131	.54	36.8	2.7

"From regression of shoot growth rate (mm/day) on daily degree-hours above 40" F for 18 nights during the spring.

Shoot growth rates per 100 degree hours (slope coefficient X 100) averaged 1.60 mm per day, with a standard deviation of 0.39 mm. There was no significant relationship between growth rates and either intercept values (r^2 = 0.113) or threshold temperatures (r^2 = 0.143).

Thermal Efficiency and Height Growth. Nearly all of the tree-to-tree differences in total seasonal height growth were associated with the two thermal efficiency parameters (Table 3). The regression of total seasonal height growth of the 10 trees on threshold temperature and growth rate had an R^2 of 0.942 and standard error of 6.6 cm. Using intercept values instead of threshold temperature resulted in an R^2 of 0.926 and standard error of 7.5 cm. The intercept coefficient was the most important single thermal characteristic and accounted for 64 percent of the variation in height growth. Growth rate alone was not significantly related to height growth. The parameters were more closely related to growth after the first flush and to total seasonal growth than to growth of the first flush. The reason may be that upper limits on first flush growth are established by the

TABLE 3. Relationships between thermal efficiency parameters and terminal shoot growth of ten sampled loblolly pines.

Thermal efficiency parameters from each sample tree	Coefficients of determination (R^2) for Growth of first flush	All growth after first flush	Total seasonal height growth
Intercept coefficient	0.386	0.594**	0.643**
Threshold temperature	.381	.562*	.617**
Slope coefficient	.066	.028	.054
Intercept and slope coefficient	.632*	.798**	.926**
Threshold temperature and slope coefficient	.662*	.797**	.942**

** Significant, 0.01 level; * significant, 0.05 level.

overwintering but, but later flushes depend only upon the current season's climatic conditions (Kozlowski 197 1) .

Discussion

The results of the present study suggest that the thermal characteristics of loblolly pine, particularly threshold temperature, may be important factors in the duration and amount of height growth each growing season. Similarly, Schütt (1970) reported that Scotch pine seedlings selected for early flushing grew more from ages 2 to 5 than those selected for late flushing.

The genetic factors that may be responsible for the variations in height growth among trees in a stand and among geographic races of southern pine that are grown together (Allen 1969, Bengtson and others 1967, Perry 1962, Wells and Wakeley 1970) have not been identified. If thermal efficiency is such an inherent characteristic of individual trees and races, it could be a key to early evaluation of growth potential, especially in relation to different climatic regimes. It also might explain some of the genotype-environment interactions that often have clouded the results of provenance trials (Wright 1973).

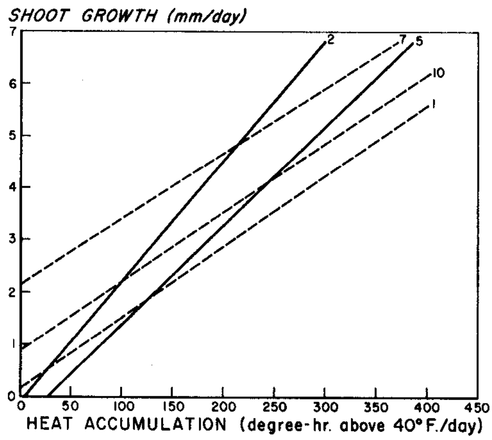

FIGURE 1. *Growth of five selected loblolly pines in response to temperature. (The numbers attached to the lines identify trees from Table 1.)*

The growth patterns of five study trees show how thermal response characteristics might combine with varying climatic conditions to produce differences in growth performance (Fig. 1). Of the three trees that have about the same growth rates-l, 7, and lo-tree 7 has the lowest threshold temperature, and tree 1 has the highest. Among these, total seasonal height growth increased as threshold temperature declined (Table 1). Trees 2 and 5 have relatively high threshold temperatures, but the disadvantage is partly offset by high growth rates. Neither grew as much as tree 7, but the growth of tree 2 exceeded that of tree 1 and nearly equaled that of tree 10. Tree 7 had the lowest growth rate, but its exceptionally low threshold temperature more than compensated for this during the year of study. The performance of trees 2 and 5 in relation to trees 1, 7, and 10 probably would change with climatic conditions, whether from place to place or from year to year in the same place. The relative performance of trees within each group should remain about the same regardless of climate.

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