# GROWTH AND STEM SINUOSITY OF DIVERSE PROVENANCES OF THREE-YEAR-OLD LOBLOLLY PINE

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Abstract.--Stem height and sinuosity of stem and of branches were measured at age three in a trial established in southwest Georgia with 13 to 16 OP families from each of four provenances of loblolly pine *(Pinus taeda L.)*. Families from the Gulf Hammock, FL provenance were taller than families from the Atlantic Coastal Plain, Lower Gulf, and Middle/Upper Gulf provenances. Sinuosity also differed significantly by provenance with the fastest growing provenances having the most sinuous stems and branches.

The unfavorable correlation between growth and sinuosity at the provenance level was not evident among families within provenances. Apparently, the mechanisms causing the faster-growing provenances to be more sinuous were not the same at the family level within provenances. We hypothesize that the large differences in the length of the growing season for trees from the different provenances are partly responsible for the differences in sinuosity. Trees from southern regions grew longer than trees from the northern regions and possibly were not as lignified, increasing the likelihood of sinuosity.

Keywords: Breeding, genetic gain, *Pinus taeda* L., stem form, wood specific gravity

## INTRODUCTION

The influence of provenance or seed source on stem form, notably straightness, has been well documented for numerous species (Zobel et al. 1987). Frequently, poor form results from the use of an incorrect seed source or provenance where a species is used as an exotic. At times, the poor form or straightness can be so extreme as to render the trees basically unusable.

Less well understood is the influence of provenance on stem form for seed movements of a less dramatics nature. Dietrichson (1964) linked latewood formation, tree heights, autumn frosts, spring frosts, stem straightness and wood lignification to provenances of Norway spruce *(Picea abies (L.)* Karst.) in Europe. Duration of growth was correlated with frost damage, latewood formation and ultimately with straightness. Latewood formation was negatively correlated with straightness with trees appearing more crooked as latewood percentage decreased. Even more significant was incomplete lignification which resulted in trees being more crooked.

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In loblolly pine, Jett et al. (1991) reported that trees from southern provenances such as Livingston Parish, LA and Florida consistently displayed low specific gravity when compared to trees from more northern sources. We postulated that the lower specific gravity of these sources might be explained by differences in patterns of shoot elongation. Zahner (1962) reported that latewood formation was not initiated until stem elongation ceased. If the southern sources grew longer than those of more northern seed lots, high density/high strength latewood would not be formed until later in the growing season, and lower wood specific gravity would result. However, Jett et al. (1991) made no attempt to evaluate growth phenology to determine the relationship of growth of these southern sources to their specific gravity. Subsequent observations of the same study trees indicated that seed source was beginning to have an impact on tree form consistent with the reports of Dietrichson (1964). This study was undertaken to determine the relationship between stem crook (sinuosity) and tree height both between and within four loblolly pine provenances.

## MATERIALS AND METHODS

Seedlings originating from open-pollinated seeds of 13 to 16 families from each of five provenances in the southeastern United States were planted in a trial that was initially used for an early selection study (see McKeand and Bridgwater 1993 for details). Families from four of the provenances -Atlantic Coastal (ACP), Gulf Hammock (GH), Lower Gulf (LG), and Middle/Upper Gulf (MUG)- were assessed for the current study. Seedlings were grown in RL Super Cells' (164 cc) in a greenhouse in Raleigh, NC until they were outplanted in March 1989 near Georgia-Pacific's (G-P) nursery at Cedar Springs, GA and at International Paper Company's (IPCo) Southlands Experiment Forest near Bainbridge, GA (Figure 1). A randomized complete block design with 36 blocks of single-tree plots of 72 families was initially used at each location. Thus, a total of 72 seedlings were planted per family. The trees were planted at a spacing of 1.3 x 1m at G-P and 1m x 1m at IPCo to minimize block sizes. No cultural treatments were imposed on the trees except that tip moths *(Rhyacionia* sp.) were controlled with periodic insecticide applications, and competing vegetation was controlled with periodic herbicide applications.

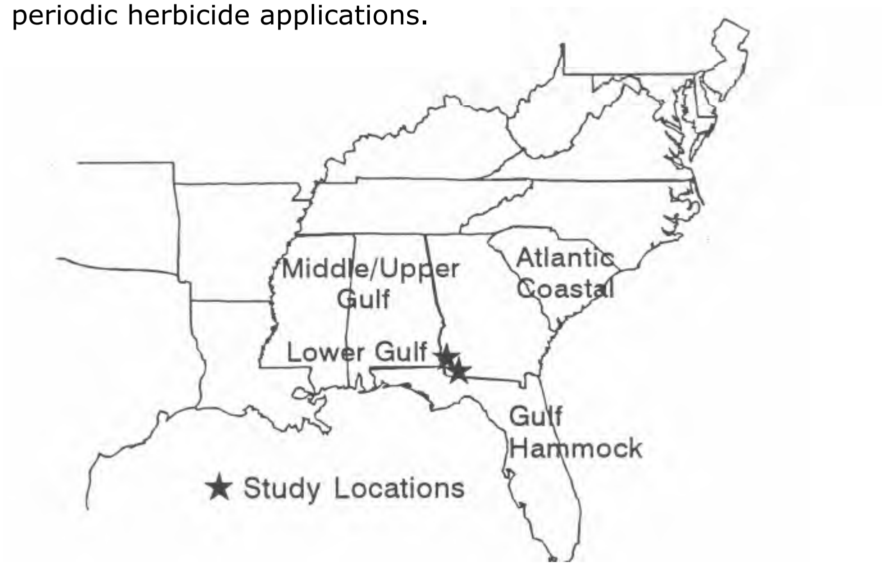


Figure 1. Map of the southeastern United States showing the general location of the four provenances and the location of the two field sites.

In February 1991, the study was thinned to allow for assessment of wood properties in subsequent years (see Anonymous 1993 for details). All trees from the Marion County, FL provenance were cut. Half the trees from the other four provenances were cut to leave one tree in each adjacent pair of blocks (e.g. original blocks #1 and #2 were considered as one block). Each family was now represented by 18 trees at the G-P site and 16 trees at the IPCo site (four of the original blocks at IPCo were dropped).

In 1993 at age 3 years, stem height, number of growth cycles (flushes), and sinuosity of the stem and of the branches were measured. Sinuosity was assessed on a three point scale: 1 = none, 2 = minor, 3 = major sinuosity. Other stem straightness defects such as crooks from broken leaders or tip moth damage were not assessed.

Family and provenance means across the two planting sites were calculated for each trait. All statistical analyses were conducted using the GLM and VARCOMP (Type I sums of squares) procedures in SAS (SAS Institute Inc., 1985). To estimate the significance levels for provenance effects in the analyses of variance (Table 1), an approximate F-test (Satterthwaite, 1946) was used. Genetic and environmental components of variance were estimated for each provenance separately. The variance among open-pollinated families within each provenance was assumed to estimate 1/4 the additive genetic variance (Falconer, 1989), and individual tree heritabilities for each provenance were calculated as:

$$h^2 = \frac{4\,\sigma^2_F}{\sigma^2_F + \sigma^2_{FL} + \sigma^2}$$

where: $\sigma^2_F$ = variance among families
$\sigma^2_{FL}$ = variance due to family by location interaction
$\sigma^2$ = variance among trees within a family within a location

Standard errors of each $h^2$ estimate were calculated using methods of Becker (1984).

Table 1. Form of the analysis of variance used in the overall analyses.

| Source | deg. of freedom | Expected Mean Squares[1] |
|---|---|---|
| Location | 1 | |
| Blocks(L) | 32 | |
| Provenance | 3 | $\sigma^2 + b\sigma^2_{LxF(P)} + lb\sigma^2_{F(P)} + f\sigma^2_{B(L)xP} + bf\sigma^2_{LxP} + lbf\Theta^2_P$ |
| LxP | 3 | $\sigma^2 + b\sigma^2_{LxF(P)} + f\sigma^2_{B(L)xP} + bf\sigma^2_{LxP}$ |
| B(L)xP | 96 | $\sigma^2 + f\sigma^2_{B(L)xP}$ |
| F(P) | 54 | $\sigma^2 + b\sigma^2_{LxF(P)} + lb\sigma^2_{F(P)}$ |
| LxF(P) | 54 | $\sigma^2 + b\sigma^2_{LxF(P)}$ |
| B(L)xF(P) | 1666 | $\sigma^2$ |
| Corr. total | 1909 | |

[1] Provenances were considered as fixed effects, all others as random effects.

## RESULTS AND DISCUSSION

At the end of three growing seasons in the field, overall mean height was 389cm, and 54% of the trees displayed some degree of stem sinuosity. Trees from the Gulf Hammock provenance were the tallest, followed by Atlantic Coastal, Lower Gulf, and the Middle/Upper Gulf. Provenance rankings for number of growth cycles and stem and branch sinuosity (Table 2) were the same as for height.

There was a relatively strong unfavorable correlation ($r_F$ =0.58) between height and stem sinuosity when families from all four provenances were compared. We hypothesize that the large differences in the length of the growing season for trees from the different provenances (e.g. Perry et al. (1966)) are partly responsible for the differences in sinuosity. If trees from southern regions grew longer than trees from the northern regions, it is possible that the southern trees were not as lignified as the northern trees, increasing the likelihood of sinuosity.

Within each provenance, there was moderate to strong genetic variation for growth and sinuosity traits (Table 3). The large family differences for stem height within each provenance was not significantly correlated with stem or branch sinuosity. Apparently, the mechanisms causing the faster-growing provenances to be more sinuous were not the same at the family level within provenances. We suspect that there is much less variation in the length of the growing season within each provenance as compared to among provenances. In a separate study, families of loblolly pine from a relatively narrow geographic range varied in height due to both duration of the growing season and rate of growth during the season (Bridgwater 1990). If stem sinuosity was mainly caused by poorer lignification because trees grew longer, a lower correlation between height and sinuosity within provenances would be expected.

Table 2. Provenance means for traits measured at age 3 years in the field.

| Trait | Atlantic Coast (16 fam) | Gulf Hammock (15 fam) | Lower Gulf (14 fam) | Middle/Upper Gulf (13 fam) |
|---|---|---|---|---|
| Stem Height (cm) | 397b | 4373 | 367' | 347` |
| Number of Growth Cycles | 4.58ab | 4.76' | 4.31' | 4.15` |
| Stem Sinuosity Score | 1.68') | 1.79' | 1.60' | 1.47' |
| % Sinuous Stems | 57.3ab | 65.8' | 54.4b | 40.9' |
| Branch Sinuosity Score | 1.833b | 2.01' | 1.671' | 1.56') |

Means within a row followed by the same letter are not significantly different (p .05).

Table 3. Individual-tree narrow-sense heritabilities (standard errors in parentheses) for traits in different provenances.

| Trait | Atlantic Coast | Gulf Hammock | Lower Gulf | Middle/Upper Gulf |
|---|---|---|---|---|
| Stem Height | 0.53(.20) | 0.40(.18) | 0.49(.21) | 0.81(.30) |
| Number of Growth Cycles | 0.25(.13) | 0.36(.16) | 0.24(.13) | 0.36(.18) |
| Stem Sinuosity Score | 0.24(.12) | 0.20(.1 1) | 0.32(.16) | 0.35(.18) |
| Branch Sinuosity Score | 0.21(.11) | 0.32(.15) | 0.27(.14) | 0.54(.23) |

The genetic correlation between branch and stem sinuosity within each provenance was essentially perfect ($r_G = 1$). If a family tended to display sinuous branches, it also had sinuous stems. This is an important relationship for breeders, since branch sinuosity is displayed more commonly than stem sinuosity (Table 2). If a tree displays sinuous branches but not a sinuous stem, there is still a strong likelihood that its progeny will have sinuous stems.

While there are potential gains in growth from utilizing southern coastal sources of loblolly pine, the associated risk of reducing stem quality and also wood specific gravity (e.g. Byram and Lowe 1988, Jett et al. 1991) must be recognized. We are continuing to evaluate the present study to determine the relationships among growth traits, stem form, wood properties, and phenology. We hope to determine why relationships may differ among the traits depending upon the origin of the families.

## ACKNOWLEDGEMENTS

This study was funded by members of the North Carolina State University - Industry Cooperative Tree Improvement Program and the United States Forest Service. We particularly appreciate the assistance provided by Georgia-Pacific Corporation and International Paper Company with the establishment and management of the trials. The assistance of Dr. Floyd Bridgwater and Mr. Chris Hunt are gratefully acknowledged.

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