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Best Paper

EARLY SELECTION OF LOBLOLLY PINE FAMILIES BASED ON SEEDLING SHOOT ELONGATION CHARACTERS

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Abstract.-- Seedlings of 23 open-pollinated loblolly pine (*Pinus taeda* L.) families and three checklots were grown in a greenhouse under two nitrogen (N) levels (5 and 50 ppm) for four months. Significant family differences were detected for the number of growth cycles, summer shoot elongation, number of stem units, and total seedling height. Positive correlations were found between family mean seedling height and 12-year height performance levels in the field, and correlations increased substantially after seedlings had set the first terminal bud. Summer shoot growth, cycle numbers, and number of stem units showed stronger correlations with field performance than seedling height. The correlations were consistently higher under the low N than under the high N condition. The height growth of 12-year loblolly pine families can be more accurately predicted by measuring summer shoot elongation of seedlings grown under the mimicry low N environment.

Keywords: *Pinus taeda* L., juvenile-mature correlation, summer shoot elongation.

INTRODUCTION

Tree breeders have recognized that tree improvement progress can be speeded up by early testing and selection if certain genetic relationships exist between juvenile and mature trees. The judgment is often made on growth rate alone without consideration of other nutritional and physiological characteristics. Research has confirmed large genetic variation in seedlings of tree species for physiological characteristics such as photosynthetic rate (Ledig and Perry 1967, Zelawski 1976, Ledig and Clark 1977), and uptake and use of nutrients (Jahromi et al. 1976, Johnson 1984, Kleinschmit 1982). Some success has been made to relate the morphological and physiological characteristics (Cannell et al. 1978, Waxier and van Buijtenen 1981) and nutritional traits (Cotterill and Nambiar 1981) with genetic potential of field growth. Family seedling shoot elongation patterns were reported to be strongly associated with 8-year height performance in the field (Bridgwater et al. 1985, Williams 1987). The height after free growth of seedlings was reported to have strong genetic association with height growth in the field (Williams 1987). A better understanding of shoot morphology in controlled environmental conditions which mimic major environmental variables in the field may be important for successful early selection (Cannell et al. 1978, Bridgwater et al. 1985).

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N deficiency is usually a limiting factor for tree growth in most forest stands, so successful juvenile selection may depend on a better understanding of various physiological processes involved with the growth under the mimicry low N conditions. Seedling growth under the mimicry low N condition may be better correlated with field performance. This study was designed to examine the genetic variation in seedling shoot growth under two contrasting N environments (N-stressed and high N), and to determine the relationship between seedling growth and 12-year height performance in the field. It was part of a larger study designed to evaluate genetic variation in N use efficiency, carbon allocation, root characters, and shoot growth patterns under low and high N, and to use these traits for early selection.

MATERIALS AND METHODS

Twenty-three open-pollinated loblolly pine families from the northern coastal plain of North Carolina and southern coastal plain of Virginia were used in the study. All families have been extensively evaluated in long-term genetic tests of the N. C. State University Tree Improvement Cooperative. In addition, open-pollinated seeds of 7-56, a consistently good family from the coastal plain of South Carolina, a bulked seed lot from unimproved stands (commercial check), and a bulked seed lot from coastal seed orchards of North Carolina were also included in the study as check lots.

A split-plot design with N treatments as whole plots and loblolly pine families as sub-plots was replicated in four blocks. Three seedlings per families were randomly distributed within each treatment-block combination. Seeds were weighed, stratified, and sown in flats, then seedlings were transplanted to 6x6x16" square pots filled with a sterilized sand medium. N treatments were delayed until the seedlings were four months old in order to avoid possible seed size or other maternal effects on early growth (Cannell et al. 1978). The two N levels, 5 and 50 ppm (equal proportion of NH_4 and NO_3), were applied about three times per week depending on leaf water potential measurements (Li 1989). Predawn leaf water potential was monitored with a pressure chamber and nutrient solutions were supplied when the leaf water potential of -0.5 MPa was reached.

Seedlings were harvested after four months of N treatments. The height, cycle number, and length of cycles were measured. Summer shoot elongation was determined *by* subtracting first cycle length from the total seedling height. A mixed linear model with N treatment effect fixed and family effect random was used for evaluation of experimental data (Li 1989). The General Linear Model (GLM) procedure in Statistical Analysis System (SAS) was utilized to analyze the data (SAS Institute 1982). Genetic variance components were estimated for half-sib families to obtain heritability estimates. Narrow-sense heritabilities were estimated for those shoot characters which showed significant family variation (Li 1989). Family mean seedling shoot characteristics were correlated with the height performance level (PL) values in the genetic tests. Performance level values were standardized values averaged over fifteen 12-year-old genetic tests of the North Carolina State University Tree Improvement Cooperative (Hatcher et. al. 1981). These tests were not balanced in terms of representing every full-sib family in the same test, but each of the 23 half-sib families was represented by an average of 17 full-sib crosses, and each family was tested in at least five tests in different environments.

RESULTS AND DISCUSSION

Family variation

There were significant family differences for all traits except the mean stem unit length at low N (Table 1). The number of stem units showed more variation than the mean stem unit length, which agrees with other studies that showed that the number of stem units accounts for most of the differences in shoot elongation for different conifer species (Bridgwater et al. 1985, Cannell et al. 1976, Kremer and Larson 1983, Kremer 1986). Heritability estimates for cycle numbers, summer shoot length, and the number of stem units were higher than those for seedling total height in both N conditions (Table 1). The number of growth cycles showed the strongest genetic control, while the mean stem unit length was under relatively weak genetic control. Heritability estimates from low N were higher than their corresponding estimates in high N. Standard errors for heritability estimates were usually less than half of the magnitude of heritability estimates, indicating that these estimates were reliable.

Table 1. Heritability estimates[1/] and their standard errors (in parentheses) for some shoot characteristics under low and high N conditions, and combined over the two N levels.

Traits	Heritability (h2)		
	Low N	High N	Combined
Cycle Number	0.94 (0.02)	0.85 (0.33)	0.94 (0.05)
Total Height	0.53 (0.25)	0.37 (0.22)	0.21 (0.11)
Summer Growth	0.73 (0.30)	0.48 (0.27)	0.56 (0.22)
# Stem Units	0.74 (0.30)	0.44 (0.23)	0.58 (0.22)
Mean Stem Unit Length		0.20 (0.14)	0.15 (0.09)

[1/] Heritabilities were calculated only for traits showing significant family differences.

Correlations with 12-year Height

Positive correlations were found between family mean seedling height and 12-year height PL in the field (Figure la), and the correlations increased substantially after seedlings had set the first terminal bud at about 4-months from sowing. Summer growth had a higher positive correlation with 12-year height than total height (Figure lb). Williams (1987) also reported that loblolly pine seedling height at the first bud was negatively correlated with 8-year height, but the correlation increased as seedlings grew in height.

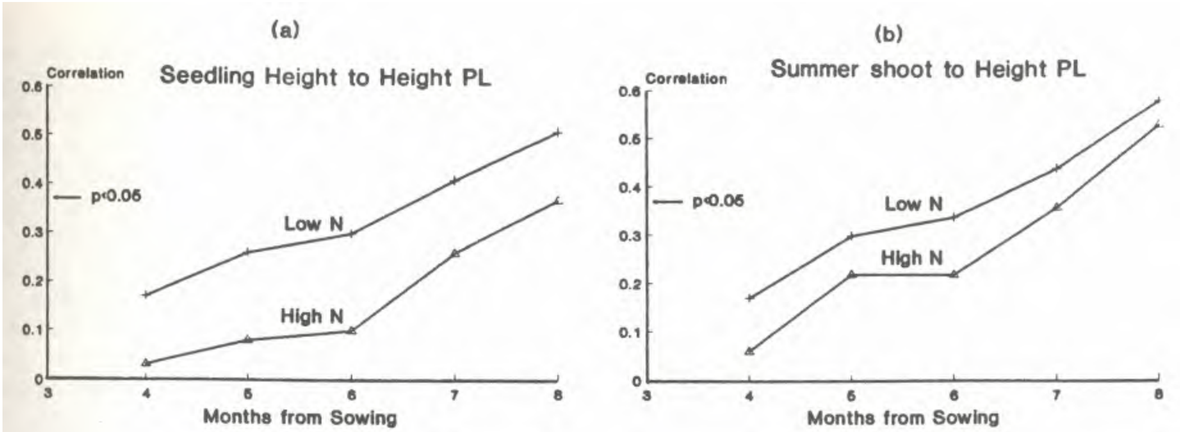

Figure 1. Family mean correlations of 12-year height PL with seedling height (a) and summer growth (b).

The low correlations in the early growing season may be influenced by seed weights. This was supported in part by a decrease in the correlation between the family mean seed weights and family mean seedling height as seedlings grew (Figure 2). Family mean seed weights were strongly correlated with seedling height at the end of free growth, but the correlations decreased after seedlings started to produce summer growth. The correlations between shoot growth traits and 12-year height PL increased as the proportion of summer growth increased over the experimental period (Figure 1). Cannell et al. (1978) also reported that positive correlations between seed weights and seedling height in loblolly pine seedlings disappeared once the seedlings exceeded about 140 mm in height. The correlation of seedling height with 8-year height increased after seed weight effects disappeared.

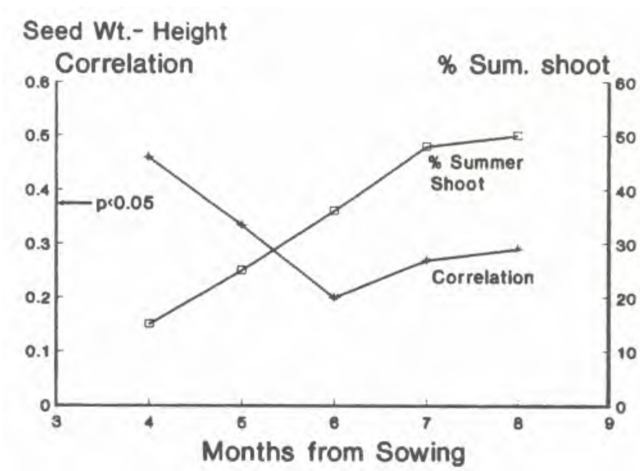

Figure 2. Family mean correlations between seed weight and seedling height over time. Also shown is the percent of total height which summer shoot growth contributes.

Mean summer shoot length, average number of growth cycles, and the mean number of stem units of 23 families showed stronger correlations with 12-year height PL in the field than seedling total height (Table 2). Families which produced more growth cycles and initiated more stem units per cycle had greater summer growth as seedlings (Li 1989), and also grew better in the field. The number of stem units had higher correlations with 12-year height than the mean stem unit lengths. The summer growth was the best predictor of 12-year height in the field. The precision of prediction could be further improved by measuring seedlings under the low N condition because the juvenile-mature correlations were consistently higher in low N than those in high N (Table 2). This supported the hypothesis that seedling families grown under low N are better correlated with field performance levels. Performance of known check lots (commercial check and 7-56) among families also supported this result. The commercial check (CC) and 7-56 had essentially the same height in the high N condition, but 7-56 produced 28% more height growth in the low N condition. Family 7-56 produced 39% more summer growth than CC at low N but only about 8% at the high N condition.

Table 2. Family mean correlations of seedling shoot characters with 12-year height performance levels for two N treatments.

Traits	Low N	High N	Combined
Total Height	0.47*	0.21	0.43*
Cycle Numbers	0.51*	0.43*	0.44*
Summer Growth	0.58**	0.48*	0.52*
# Stem Units	0.54**	0.35	0.47*
Mean Stem Unit Length	0.02	0.18	0.13

*, ** : Significantly different at p<0.05 and p<0.01, respectively.

The stronger correlation at low N indicated that 12-year height of loblolly pine families could be more accurately predicted from the seedlings grown under the low N condition than under the high N condition. The improvement in correlations by measuring seedlings under low N could be due to the influence of low N availability on family differences in 12-year height in the field conditions. In fact, the low N level in this experiment was similar to that in the field conditions in terms of N concentration in the tissues. N concentration of the seedling needles on the average was 0.9% in low N and 1.8% for high N. This was close to the average foliar N concentration (0.8 - 1.2%) reported for 2-year-old loblolly pine seedlings of non-fertilized plots across a range of sites (NCSFFC 1984). Thus, the low N (5 ppm) was considered as a mimicry N-stressed environment in the field, while the high N (50 ppm) was a N luxury environment which was not a common field condition for loblolly pine genetic tests. The efficiency of early selection is expected to increase under this mimicry low N condition because of higher heritabilities and juvenile-mature correlations.

Other studies also showed the possibilities for early selection under the mimicry environmental conditions. The growth rate of loblolly pine seedlings was shown to be significantly correlated to field stem volume of the same families at age 8 when seedlings were grown under similar moisture conditions as in the field (Cannell et al. 1978). Seedling height grown under growth-accelerating environments (high fertility and supplemental lighting) had no correlation (r = 0.13) with 8-year height, but seedlings grown under more natural day length environments showed strong correlations (r = 0.59) with 8-year height in the field (Williams 1988).

Based on these results and others (Bridgwater et al. 1985, Li 1989, Williams 1987), it seems that operational tree improvement programs can utilize these measures of seedling shoot elongation for early selection. First, this can be used to screen parents in the breeding population before crossing, or to eliminate the poorest crosses before field progeny testing. The cost of breeding and field progeny tests can be reduced substantially or more individuals of each cross can be tested in the field. Secondly, this procedure can be used to increase the precision of selections. The seedlings of the same families which have been tested in the field can be grown in the greenhouse for evaluation. A selection index could be used to combine field information and greenhouse evaluation for selection. Furthermore, the combination of the shoot elongation traits with other seedling characters (root morphology and N use efficiency) showed promise to further increase the precision of predication (Li 1989).

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