FIRST-ORDER LATERAL ROOT DEVELOPMENT: SOMETHING TO CONSIDER IN MOTHER TREE AND PROGENY ASSESSMENT

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Abstract.--Recent work on frequency distribution and heritability of first-order lateral roots (FOLR) of loblolly pine and sweetgum seedlings suggests the desirability of using specific root characteristics of seedlings as a supplement to assessment of stem dimensions. For 3 years we have tested progeny from approximately 75 mother trees in Georgia Forestry Commission seed orchards. Frequency distribution of progeny by FOLR number appears to be highly heritable. Seedling height and root-collar diameter are readily altered by certain cultural practices such as fertilization, top clipping, and root pruning. But, within a standard seedbed density range, numbers of FOLR were affected little by changing cultural practices. At lifting, seedlings could be found with good stem characteristics and poor FOLR development. However, regardless of nursery conditions, few seedlings with excellent FOLR development had poor aboveground development.

Results suggest that it may be possible to select superior mother trees by rating number of FOLR on their progeny produced under specific nursery conditions. Less than 20% of the progeny of some trees have <3 FOLR; more than 60% of the progeny of others have <3 FOLR. If results of ratings of these progeny in current field trials coincide with our nursery ratings, we will likely have an additional tool to identify the best mother trees in pine seed orchards.

Keywords: Root morphology, tree improvement.

INTRODUCTION

The Tree Improvement Programs (TIP) in the United States are perhaps the most important innovations in forestry in this half century. In the Southern United States, tree improvement efforts have been concentrated on southern pine species. Extensive seed orchards of selected mother trees and highly mechanized nurseries are integral parts of advanced plantation technology that the TIP made possible.

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One of the major benefits expected from TIP was greater uniformity and higher quality of planting stock. Early research showed that large seedlings tended to perform better than small ones after outplanting and one improvement objective was to increase the percentage of large seedlings in nurseries (Wakeley 1954). Since the mid-1960s, improvement in nursery practices has resulted in marked increases in average seedling size. However, many of the seedlings produced were too large for conventional planting operations, and uniformity was often lost because faster growing seedlings interfered with the development of the slower growing ones. Eventually, some degree of seedling uniformity was restored by mowing seedling tops several times during the latter part of the growing season (USDA Forest Service 1985).

Producing a high percentage of seedlings within specific size ranges became synonymous with improved seedling quality. If seedlings were uniform in size, they were plantable. Now, after 25 years, we recognize that early expectations from improvement in seedling quality are not being realized. To obtain loblolly pine stands of desired stocking, foresters routinely overplant by 40% because experience has shown that a significant proportion of the planted seedlings are usually not competitive. Unfortunately, survival patterns cannot be predicted, so plantation are often overstocked in some places and understocked in others. The conclusion stated by the Southern Industrial Forestry Council (1984) appears valid: "the failure to produce and to recognize seedlings with consistently high establishment and growth potential are major obstacles to successful plantations in the reforestation programs in the southern United States".

Current research at the Institute for Mycorrhizal Research and Development (IMRD) project at the USDA Forest Service Forestry Sciences Laboratory, Athens, Georgia, shows that a significant proportion of the progeny tested in nursery beds, even among phenotypically selected superior mother trees, develop few first-order lateral roots (FOLR). We have found that for either single mother tree progeny or seedlings from mixed seedlots of commercial origin, seedlings with <3 FOLR are less competitive in the nursery than those with greater numbers of FOLR.

In this paper we describe some of our research on FOLR frequency distributions of 1-0 bare-root loblolly pine seedlings.

Seedling Production

For the past 4 years loblolly seedlings were tested at the IMRD experimental nursery located near Athens and maintained in cooperation with the School of Forest Resources, University of Georgia, Athens. Seedbed density was maintained at approximately 275/m^2 regardless of fertility practices. The seeds were collected from individual mother trees in the Georgia Forestry Commission's Arrowhead and Baldwin seed orchards. The seedlings were grown in concrete block nursery beds (1.22 m x 18.29 m) with a 25 cm gravel base covered by a 6 mil black polyethylene barrier. Above the barrier *was* 50 cm of a soil mixture (2:1:1) of loamy forest topsoil, sand, and finely ground pine bark.

Since soil fertility varied from year to year, available soil P (Bray II) and K were adjusted each year to 50 to 75 ppm P and 80 to 100 ppm K. Calcium was maintained in the range of 390-500 kg/ha. Nitrogen was applied in 3 to 5 small applications per year totaling 60 to 160 kg/ha with the final application by mid-July. During germination and initial seedling growth beds were watered frequently as needed, but once seedlings were well established they received 2.5 to 3.0 cm of water per week as rain or supplemental watering.

Seedlings were evaluated in mid-January, and diseased or mechanically damaged seedlings were discarded (usually only 1% of the seedlings). In most tests data were taken on the first 100 seedlings lifted from each family per replicate. Height, root collar diameter (RCD), and number of FOLR were recorded for each seedling and a subsample of eight seedlings per replicate was obtained for destructive sampling. The subsample was divided into four FOLR categories (0-3, 4-5, 6-7, and >8) that permitted these data to be approximately proportional to the population. Seedlings of mixed seedlot origin provided by two to four state or industrially operated nurseries were also tested and their FOLR frequency distributions compared closely to the theoretical one reported in Kormanik and Muse (1986).

RESULTS AND DISCUSSION

Experimental Nursery Results

The yearly combined FOLR frequency distributions of the progeny from all family seedlots tested during these 4 years compared favorably with the theoretical distribution developed and reported earlier (Kormanik and Muse 1986). In all of the more than 70 families of progeny that were tested, the relative competitive position of seedling in the nursery was correlated with FOLR numbers; in each sibling group, the smallest seedlings had the fewest FOLR. Family mean heritability estimates for FOLR numbers have been uniformly high in all tests. The average family mean heritability estimates have been 0.76+0.11 for the different families tested (Kormanik, unpublished data).

While the combined FOLR frequency distribution compared favorably to the theoretical distribution, the individual family distribution did not. Some families produced a high percentage of "carrot-rooted" individuals while other families produced a low percentage. This variation was quite evident in the quality and uniformity of the seedlings within specific half-sib progeny groups. The spread between a poor and a good family, based on FOLR frequency distribution is shown in Figure 1. The better families have fewer than 25% of their progeny with <3 FOLR, but the poorer families have about 60% of their progeny in this group. Within all families tested, seedlings in the 0-3 category have always been significantly smaller than those in the other three categories. The combined mean data from the 1987 nursery experiments when 25 different mother tree seedlots were used are shown in Table 2. Families 7 and 3 (c.f. Fig. 1) were two of the 25 families.

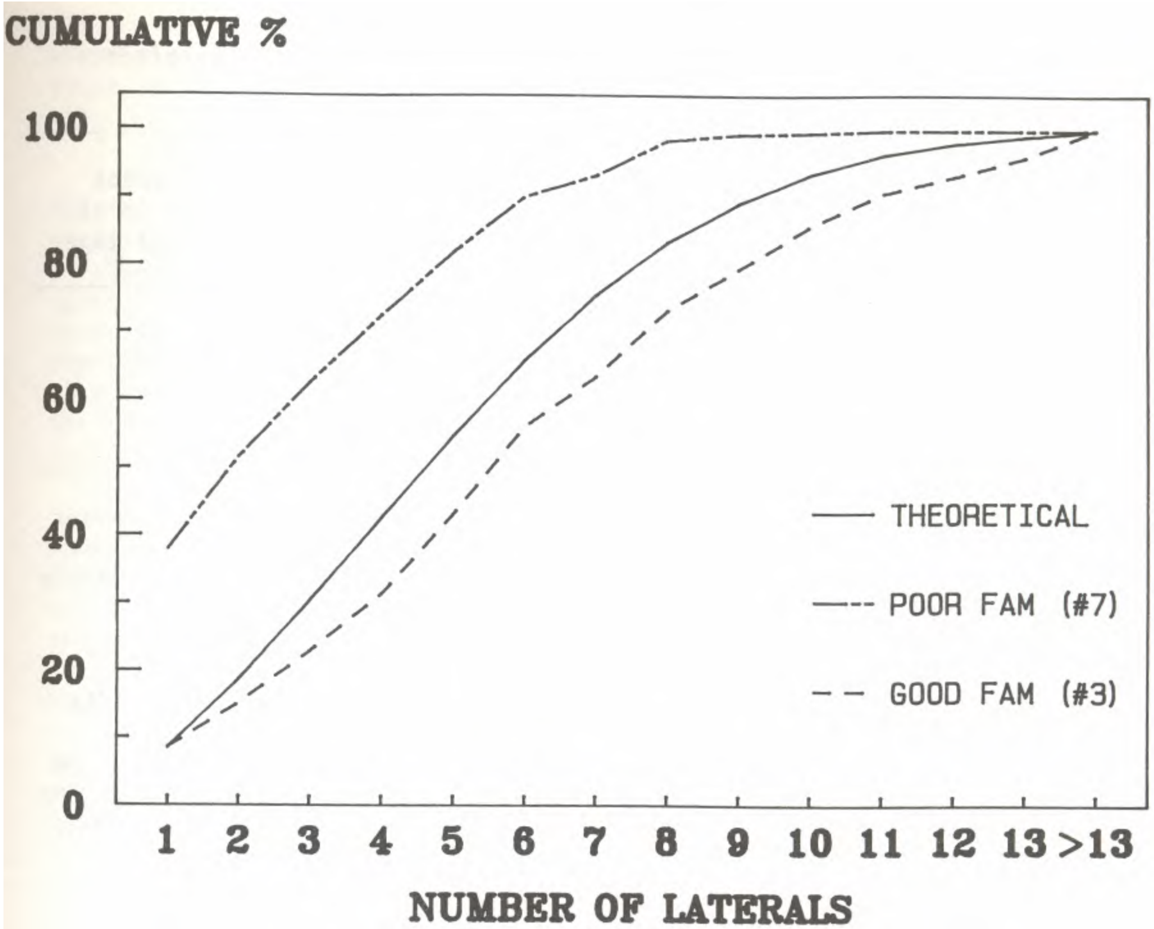

Figure 1. Theoretical frequency distribution of loblolly pine seedlings based on counts of first-order lateral roots compared with distributions developed from seedlots from a good (#7) and a poor (#3) mother tree.

Seedlings from the 1987 trial were quite large because they were not sheared in the nursery bed to conform to some predetermined optimum size. Even those in our 0-3 FOLR category would, on the average, qualify as Wakeley (1954) grade 2 seedlings. Grade 2 seedlings are generally considered to be among the best ones produced. Under our test conditions, seedlings with 0-3 FOLR have proven to be noncompetitive against their own siblings, even under ideal nursery growing conditions.

These differences in seedling quality evaluation based on different criteria illustrate the difficulty encountered in judging seedling quality based upon stem morphology. The obvious measures of "stem morphology" are height, which is easily obtained and maintained through fertilization and top shearing, and RCD. What of the other seedling morphological characteristics common to what Wakeley (1954) considered his "cull" or class 3

Table 1. Evaluation of loblolly pine seedlings from 25 families after lifting from the nursery beds.*

Number of lateral roots	Height (cm)	Root-collar diameter (mm)	D2H (cm3)	Average number of lateral roots	Percent of total seedlings
0-3	38.4b**	3.8d	6.25d	1.47d	39
4-5	46.5a	5.4c	14.06c	4.56c	20
6-7	49.1a	6.0b	18.64b	6.44b	17
>8	50.1a	7.1a	26.43a	9.96a	24

* Top weight, root weight, and total weight were determined by measurement of representative subsampled; each subsample contained 100 seedlings.
** Within columns, values followed by the same letter are not significantly different (P = 0.05) according to Duncan's multiple range test.

seedlings? How would the morphology of our large seedlings with few FOLR compare to Wakeley's cull individuals? Wakeley's cull seedlings were usually less than 12.7 cm tall; less than 0.32 cm in RCD; their stems were weak, often juicy and lacking mature bark. Primary single needles with few mature needles in fascicles and often having a bluish color; terminal buds were rarely present. These undesirable morphological characteristics, other than height and RCD, were common to a high percentage of seedlings in the 0-3 FOLR category in all tested families.

These various morphological traits, common to the least desirable individual seedlings of radically different sizes, appear to have biological implications worth considering in assessing other mother tree attributes. It appears that poor development of FOLR may just be a part of the genetic makeup of individual seedlings that is also expressed in the other questionable morphological attributes. Thus, a smaller percentage of progeny with few FOLR would be a valuable asset for mother trees to have when combined with other desirable characteristics.

If there is no biological implication to FOLR development, then our failure to identify quality seedlings before they have performed in the field will continue to be a problem and source of frustration. However, predictability of FOLR development coupled with the other undesirable traits, suggest that some standard nursery practice can be readily developed that could be useful for assessing selected mother trees before including them in seed orchards.

<u>Operational Nursery Observations</u>

The nursery seedlings used in this research were randomly selected from the nursery beds. The seedlings were grown under a variety of soil conditions, fertility regimes, and seedling bed densities. Some of the nursery beds were not sheared but other beds were sheared either once or twice in late summer. Seedlings in some beds were root pruned; others were not.

Shearing has an impact on seedling stem morphology but may not significantly impact the FOLR frequency distribution. In general, the sheared seedlings' last growth increment lacked needles in fascicles and few had developed terminal buds when they were lifted. Since mowing was used to control height, seedlings with few FOLR were generally similar in height to those seedlings with many FOLR, but RCDs were somewhat smaller. In our experimental nursery, seedlings with few FOLR could generally be identified by a combination of seedling height and needle characteristics. This was not the case following shearing since many seedlings had both primary foliage and mature needles in fascicles.

Roots were undercut in different nurseries for different purposes. Sometimes roots were undercut to stress the seedlings, stopping height growth and inducing bud development that was delayed because of shearing. Other nurserymen sheared to improve root fibrosity. In either case, stressing of loblolly pine seedlings in the fall can severely impact carbohydrate translocation and metabolism in roots and thus impact diameter of FOLR. However, a single undercutting in early fall after terminal bud set does not appear to adversely affect FOLR development and significantly improves root fibrosity and feeder root development. We have not observed responses of siblings to undercutting since the few seedling lots examined were of mixed seedlot origin. However, if undercutting is used to stimulate terminal bud set on sheared seedlings, we might expect that FOLR frequency distribution of seedlings would be affected.

The only nursery growing condition in which the seedlings' observed FOLR frequency distribution consistently differed from the theoretical one was that related to high seedbed density. Seedlings grown at high bed densities had fewer FOLR and their roots were uniformly smaller. High density even appeared to impact the depth to which the taproot penetrated. Most nurseries did not have excessively high densities. The problem in evaluating the operational seedlings was the sporatic occurrence of excessive bed densities. High seedbed densisties also impacted stem morphology in a predictable pattern, making assessment of quality based on stem characteristics somewhat difficult. Seedbed densities in excess of ca 320/m2 generally resulted in a significant increase in the proportion of seedlings with 0-3 FOLR. We feel this reduction in FOLR size was a direct result of competition as few mature needle fascicles developed on the lower portion of the stem when stem density was too high.

CONCLUSIONS

Within sibling populations, seedlings with the fewest FOLR are the poorest competitors in the nursery. Our seedlings having few FOLR, although three times larger than Wakeley's (1954) grade 3 culls, share many undesirable morphologial traits: primary needles, succulent stems lacking nursery beds were not sheared but other beds were sheared either once or twice in late summer. Seedlings in some beds were root pruned; others were not.

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LITERATURE CITED

Kormanik, P.P., and H.D. Muse. 1986. Lateral roots a potential indicator of nursery seedling quality. P. 187-190 in TAPPI Proc. Res. and Dev. Conf., Raleigh, NC.

Southern Industrial Forestry Research Council. 1984. Am. Pulpwood Assoc., Inc. and South. Forest Prod. Assoc., South. Ind. For. Res. Counc. Rep. 3, 15 p.

USDA Forest Service. 1985. Southern pine nursery handbook. USDA For. Serv., Southern Region Cooperative Forestry, Atlanta, GA.

Wakeley, P.C. 1954. Planting the southern pines. USDA For. Serv. Agric. Monogr. No. 18, Washington, DC.