CAN LATERAL ROOT CHARACTERISTICS BE A MAJOR FACTOR IN ASSESSING SEEDLING QUALITY

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Abstract.--A grading standard for tree seedlings should be an easily observed or measured characteristic that is strongly indicative of performance after outplanting. Lateral root morphology may be such a characteristic. Recent work with sweetgum indicates that at least four strong lateral roots may be needed to make a seedling competitive for artificial regeneration. Tests with scores of half-sib seedlots indicate that at least 40 percent of the nursery seedlings produced may not have this number of lateral roots developed when they are lifted for planting.

Additional keywords: Root grading, root morphology, sweetgum.

Seedling Quality: What is it? Although foresters readily agree on the need for quality seedlings for outplanting,few would have enough confidence to write a prescription for judging seedling quality in the nursery. The need for production of quality seedlings is certainly well known and equally well documented (SIFRC 1984, Duryea and Landis 1984, Wakeley 1954). There are, unfortunately, no reliable criteria for assessing seedling quality for any species of forest tree. This lack of agreement on what constitutes seedling quality has both land and nursery managers in a serious dilemma. Development of the technology to assess seedling quality is among the highest priorities throughout the United States and it is particularly important in the South because of the large acreages of trees being artificially regenerated (SIFRC 1984).

In the early 1920's and 30's morphological grading of southern pines seemed most promising, and it seemed to be working (Wakeley 1954). As the grading procedure became well accepted and more universally applied during the 1930's, erratic performance of graded seedlings began to appear in many field locations. It soon became apparent that nursery locations, different soil and management practices were altering seedling development enough that morphological grades from different nurseries were no longer comparable and uniform (Wakeley 1954).

By the early 1960's as the costs of nursery stock began to increase and when seed from genetically improved stock became more widely used, erratic plantation performance became a major concern of land managers. Improved techniques in nursery management did little to improve field performance of planted seedlings, even those grown from improved seedlots. Over a period of years, different criteria for judging seedling quality were offered but these proved to be of limited value and now seedlings are sold predominantly by weight.

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No attempt will be made here to thoroughly cover the seedling grading standards that have been proposed, but they generally can be classified as assessments of either morphological traits or physiological attributes. These seedling characteristics may carry the classification of Material Performance Attributes (Ritchie 1984), Stock Type, or Physiological Condition (Duryea 1984). Morphological criteria--something that is readily visible to the naked eye or easily measured or assessed--for grading all planting stock is more desirable than expensively obtained physiological parameters from a few seedlings. Wakeley (1954), however, pointed out that any nursery practice which improves the physiological status of nursery stock will also materially alter the morphological grade of the seedlings and he felt the best future for grading seedlings would have to rely heavily on some physiological criteria.

Land managers generally use morphological grades and many feel that root collar diameter (RCD) is the best measure of seedling quality. However, Webb (1969) cautioned against using RCD as a grading criteria for sweetgum (*Liquidambar styraciflua* L.) seedlings because seedlings grown at different nurseries or even from the same nursery but at different seedbed densities varied considerably in RCD.

The questionable reliability of seedling physical measurements as a grading criteria may be responsible for Burdon and Sweet's (1976) comment that land managers aren't really interested in nursery performance of seedlings but desire some measurable attribute on seedlings from the nursery that is well correlated with later field performance of planted seedlings. They concluded that possibly genotypic differences might be found within populations of seedlings that could be used to improve field performance. Any morphological trait that varies by nursery location or is readily altered with fertility practices would be of questionable value.

During the past 7 years working with sweetgum at the Institute of Mycorrhizal Research and Development (IMRD), Athens, Georgia, we feel that a relatively stable morphological root relationship has been found that may be of value in assessing seedling quality and which may be suitable for use in grading sweetgum nursery stock. It can he of value in realistically assessing the percentage of plantable seedlings one could expect from a given nursery and might be helpful in judging mother trees before they are established in orchards. Preliminary data suggests that comparable lateral root assessments may he equally common and readily recognized on seedlings from most forest tree species.

Early Nursery and Field Experiments

Beginning in 1973 and through 1978, numerous nursery experiments were run on sweetgum and other hardwoods at the U.S. Forest Service's experimental nursery maintained at the University of Georgia's Whitehall Experimental Forest. The purpose of these experiments was to determine the effects of different vesicular-arbuscular mycorrhizal (VAM) fungi and fertility regimes on seedling development. In general, these experiments showed that hardwood seedlings did not develop normally in the absence of VAM fungi when concentrations of available soil phosphorus were low (12 to 25 ppm, Bray II) (Kormanik and others 1977, 1982, Schultz and others 1981). When available soil P exceeded a level near 75 ppm, however, seedling growth was not adversely affected by the absence of mycorrhizae. If available soil P was in the range of 50 to 75 ppm, about 95 percent of the mycorrhizal sweetgum seedlings exceeded the minimally acceptable RCD limits of from 0.64 cm for outplanting. A comparable percentage of plantable nonmycorrhizal sweetgum seedlings was produced when available soil P was in excess of 100 ppm.

On the average early performance of mycorrhizal and high P nonmycorrhizal seedlings were about the same--rather poor. To find out why, additional sweetgum plantations were established on the Savannah River Forest Station, Aiken, South Carolina, in 1977 and 1978. Fifty to sixty percent of the planting locations in these plantations were occupied by two seedlings planted about 30 cm apart. The plan was to excavate one of each pair without excessive damage to the roots of the other. The original purpose of these excavations was to follow vesicular-arbuscular mycorrhizal development in seedlings after outplanting and to correlate stem growth with degree of mycorrhizal development observed. Within 6 to 8 weeks after plantation establishment, we observed that all seedling roots, regardless of original nursery treatments, had comparable mycorrhizal development. This comparability in mycorrhizal development was not accompanied by uniform growth or survival of seedlings from within the different nursery treatments. We found that a seedling's development appeared to be correlated with the number of lateral roots on the excavated seedlings. Unfortunately, when these early plantations were established our primary concern was the presence or absence of mycorrhizae on the seedlings when they were lifted from the nursery. It was later that I thought of assessing lateral root development.

From 1978 through 1981, 8,000 to 10,000 seedlings a year from four to six different half-sib sweetgum seedlots were grown and lifted separately at the IMRD Experimental Nursery at the Whitehall Experimental Forest. All seedlings were grown in the same 8 to 12 nursery beds each year at a seedbed density of $62/m^2$ (ca $6/ft^2$). Fertility and mycorrhizal variables differed somewhat among years.

The purpose of these early experiments was to develop a preliminary prescription for grading sweetgum seedlings based primarily on number of permanent lateral roots. Over the years, we had come to recognize at least three distinct types of lateral roots occurring along the taproot of sweetgum. The first are small, thin feeder roots seldom exceeding 2.5 cm in length which are uniformly distributed along the entire taproot. A second type has a similar spacial distribution, but lacks rigidity, are threadlike and can attain lengths of up to 12 cm. Some of these roots have diameters exceeding 1mm and have attached many small feeder roots of varying lengths up to about 1.0 cm. The third type, which we consider to be a part of the permanent lateral root system, develops primarily within 20 cm of the root collar. These roots are rigid and have diameters from 1 to 5 mm, lengths exceediny 35 cm, and higher orders of branching upon which abundant terminal feeder roots develop. Only the permanent lateral roots generally withstand the rigors of lifting and packaging in the nursery.

Based on data collected from field excavations, we developed a preliminary prescription for grading sweetgum nursery stock based primarily on the number of recognizable permanent lateral roots present on a given seedling. The poorest (grade 3) seedlings were those with three or fewer permanent lateral roots. The intermediate (grade 2) seedlings had from four to six permanent lateral roots while the best (grade 1) seedlings have seven or more permanent lateral roots. In these early nursery studies where percentage of seedlings in each grade was being evaluated, seedlings were destructively sampled and no plantations were established. We simply wanted to determine how nursery fertility and different mycorrhizal symbionts affected lateral root development for half-sib seedlots. At this time we suspected that nursery management practices would alter root morphology as clearly as it did stem morphology.

Results from Early Nursery Experiments

In 4 years of nursery testing of 18 different half-sib seedlots, the number of grade 3 seedlings ranged from about 35 to 60 percent for different seedlots. The average number of grade 3 seedlings annually approached about 50 percent. Specific half-sib seedlots were tested annually in up to 10 different nursery treatment combinations. We found that the distribution of seedlings by root grade was comparable across all treatments for a given half-sib seedlot, even when VAM and fertility treatments resulted in seedlings with ranges of mean heights of 0.75 m to 1.0 m and mean RCD of 0.25 to 1.1 cm.

Nursery practices significantly increased seedling size, but the increases obtained in RCDs were not normally accompanied by the development of more permanent lateral roots. More important, however, even the best mother trees produced a high percentage of "carrot-rooted" progeny--those with fewer than three strong lateral roots. This information may be of considerable importance for it suggests that regardless of improvement in nursery seedling stem characteristics, a significant percentage of seedlings may not be genetically capable of being competitive in nature because of limitations in root development.

During this early testing, seedlings from a mixed seedlot in a state nursery and one industrial nursery were also evaluated. In both nurseries, approximately 45 percent of the seedlings graded had three or fewer permanent lateral roots--figures comparable to those observed in our nursery testing.

Current Testing

In each of the 1982 and 1983 growing seasons, seedlings from four half-sib seedlots were grown in nursery beds receiving eight different treatment combinations. Seventy-eight seedlings were randomly selected from each seedlot/treatment combination in both years to provide data on root grade distribution. Four thousand seedlings from the 1982 nursery test were outplanted in a field study with a split plot design in which the effects of both nursery treatments, seedlots and root grades, could be evaluated. From the four 1982 seedlots, the grade 3 seedlings represented 53, 58, 48, and 50 percent of the seedlings produced. There were no biologically significant differences among treatments. Table 1 contains nursery seedling information for each half-sib seedlot for all nursery treatment combinations as well as first year growth and survival data for seedlings from all three grades.

Table 1.--Height and root collar diameter (RCD) of lifted seedlings, and height, RCD, and survival at the end of the first growng season in the field, by half-sib seedlot and root grade

Treatment and	Initial size		End of growing season		
root grade	Height	RCD	Height	RCD	Survival
	m	cm	m	cm	percent
80-5B					
Grade 1	1.04a	1.31a	0.87a	1.30a	84a
Grade 2	1.02a	1.10b	0.65b	0.96b	68a
Grade 3	1.00b	0.80c	0.40c	0.58c	52c
81-12B					
Grade 1	1.04a	1.34a	0.73a	1.18a	74a
Grade 2	1.04a	1.16b	0.58b	0.89b	64b
Grade 3	1.02a	0.85c	0.29c	0.52c	49c
81-3U					
Grade 1	1.04a	1.35a	0.82a	1.26a	80a
Grade 2	1.05a	1.12b	0.53b	0.81b	72b
Grade 3	1.02b	0.80c	0.33c	0.55c	52c
81-5U					
Grade 1	1.10a	1.41a	0.82a	1.32a	78a
Grade 2	1.11a	1.17b	0.57b	0.90b	66b
Grade 3	1.09a	0.82c	0.32c	0.57c	50c

Within columns and treatments, values followed by the same letter do not differ significantly (P = 0.05) according to Duncan's New Multiple Range Test.

Even though grade 3 seedlings would qualify as plantable stock by current standards for sweetgum, their survival percentage was not acceptable by any standard. Drought was severe through most of the spring and summer of 1983 in the Piedmont of South Carolina and Georgia. Survival in this plantation was poor as it had been in all plantations in those areas. The drought impact, however, was far more severe on seedlings with few lateral roots. Second-year data have not been statistically analyzed, but it appears that the relatively poor performance of root grade 3 trees is unchanged from the previous year. Seedlings from the two better root grades are growing well and, with some half-sibs, it is difficult to distinguish between them. Some half-sib grade 2 seedlings show greater variation in stem development than is apparent in grade 1 half-sib seedlings. This variation within grades may be reduced when new data are available for determining how many lateral roots are required for a seedling to be competitive.

The results from the 1983 nursery trials were similar to those obtained in the 1982 tests. Heights averaged ca 0.91 m with no biologically significant difference among grades. The RCDs for grade 3 seedlings in 1983 averaged 0.90 cm, which was significantly smaller than the 1.17 cm obtained from the root grade 1 seedlings. However a 0.90 cm diameter would be acceptable under present sweetgum grading standards. Half-sib seedlot 81-12B was used in both the 1982 and 1983 nursery trials. Among the eight VAM-fertilizer treatments in 1982, an average of 58 percent of the seedlings from this seedlot were placed in root grade 3. Comparable treatments used in 1983 resulted in 52 percent of the seedlings from this seedlot being placed in this group. The percentage of grade 3 seedlings from the other three 1983 half-sib seedlots were 36, 41, and 47.

Where Are We and Where Do We Go From Here

Our research to date indicates that the percentage of grade 3 seedlings in a seedlot is quite stable and predictable. It appears that the number of lateral roots that develop on individual seedlings may not be significantly altered by fertility practices. At low fertility levels, although the seedlings are smaller and the diameters of their permanent lateral roots are smaller, we still were able to separate seedlings into different morphological root grades. Under higher soil fertility regimes the seedlings were larger and the permanent lateral roots were also larger but we were still able to separate them from other emphermal lateral roots. Based on examination of seedlings sent to the Forestry Sciences Laboratory, Athens, Georgia, from different nurseries, soil texture appears to have limited affect on lateral root numbers and distribution. Both soil fertility and soil texture, of course, can affect the feeder root development but this has not affected the number of permanent lateral roots produced in our tests.

We now need to determine how extremes in seedbed density affect the development of permanent lateral roots and our ability to distinguish root grades. This is the objective of the 1985 nursery testing program. We do know, however, that diameters of lateral roots of seedlings in the interior of the beds are significantly smaller than those seedlings lifted from the exterior border rows. The data do not indicate, however, that the number of lateral roots from the border rows represent a different distribution than occurs on the interior seedlings. Within a given half-sib seedlot, I do not believe it is very important how big the permanent lateral roots are initially, within reasonable limits, but rather how many are present just as long as we can identify them as permanent or emphermal.

There is little doubt that there exists a distinct distribution of lateral root grades on sweetgum seedlings lifted from the nursery. This distribution appears to be stable from selected half-sib progeny and a comparable distribution has been found with seedling populations obtained from mixed seedlots of unknown parentage. Extensive nursery trials show that 40 to 50 percent of all seed germinated produce seedlings with fewer than four permanent lateral roots, which may be a minimum for satisfactory early plantation performance. This assumption must be tested in the field over time but two sweetgum plantations established in 1982 and 1983 appear to support it.

The ease with which aboveground characteristics can he changed without altering lateral root characteristics may in part explain why improved nursery practices, even with seed from selected trees, have not resulted in improved performance of nursery stock in the field. If lateral root distribution is positively correlated with plantation performance, a biological grading scheme may he fairly easy to develop. Standards, of course, will probably vary by species. Our early data indicate that lateral root characteristics are quite different for the seven different commercially important forest species we have examined. Six lateral roots may be sufficient for sweetgum seedlings to be competitive, but oaks (*Quercus* spp.) and black walnut (*Juglans nigra*) may need twice this number.

Recent surveys indicate that productivity of plantations is not as good as predictions indicated. The cause may be production of seedlings with large tops but without accompanying large root systems. If we are correct in our assumption that number of lateral roots occurring on young seedlings is a good estimator of potential productivity of that seedling and that this trait may be predictable within a given species, the economic gains in yield per hectare would warrant extensive trials of biological grading. Unfortunately, at this time, we may not be able to alter root morphological characteristics as readily as we can change aboveground characteristics. Thus, we must determine how important lateral root development of seedlings really is and be prepared to cull many seedlings if marginal plantation performance is shown to be correlated with lateral root development.

What is a quality seedling? Could it be one with at least a specific number of lateral roots?

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