Controlling Loblolly Pine Seedling Growth through Carbon Metabolism Regulation rather than Mechanical Procedures

Paul P. Kormanik[1], S. Susana Sung[1], and Taryn L. Kormanik[2]
[1]Research Forester and Plant Physiologist, Institute of Tree Root Biology, Forestry Sciences-Laboratory, Athens, GA 30602 and [2] Graduate Student, Department of Agronomy, University of Georgia, Athens 30602

Abstract.--Nursery soils should be managed to maintain desirable ranges in essential plant nutrients, organic matter, and available water for the species being produced. In many cases, however, soil fertility and available water far exceed the amounts needed to produce loblolly pine seedlings of the size range required for artificial regeneration. Top clipping and root pruning or wrenching are typically used to restrict seedling development to target ranges. Clipping, however, significantly modifies seedling morphology and prevents quality estimation with Wakeley's morphological grades. Reducing baseline soil fertility and total N top dressing did not consistently produce seedlings with reasonable height and root collar diameters. In almost all cases, seedling height and diameter exceeded planting restrictions. Research in carbon metabolism revealed that the seasonal growth patterns for loblolly pine seedling tops and roots are quite different. Top growth is active through summer and early fall whereas root growth dominates in fall and early winter. It is, therefore, possible to regulate either top or root development by the timing and amount of N and water application. In essence, we recommend controlling seedling development by regulating carbon metabolism. Our approach-is cheaper than mechanical means and results in early and consistent bud development, and a more uniform and natural top/root ratio. In traditionally operated nurseries genetically noncompetitive seedlings have the chance to grow to a reasonable size, but these seedlings do not perform well after outplanting. With our protocols, these noncompetitive seedlings are easily identified at lifting. Our protocols reduce water use and the risk of ground and surface water contamination caused by excess fertilization, especially with nitrates.

## INTRODUCTION

Loblolly pine are the most numerous conifer in forest tree nurseries throughout the Southern United States. Nursery practices have been altered in the last 50 years to accom odate the production of high-quality loblolly seedlings. Unfortunately, quality is often equated to size. When Wakeley (1954) popularized the concept of assessing seedling morphology in the early 1930s, nursery practices were primitive by current standards and few effective chemical. treatments were available for pest control. Southern nursery soils usually were fertilized with partially decomposed plant materials and animal manures. Under these conditions, Wakeley (1954) showed that root-collar diameter (RCD), height, needle characteristics and terminal bud development could be valuable in predicting the competitive potential of loblolly pine seedlings when lifted from the nursery beds.

Early efforts to grade nursery seedlings, therefore, were successful. That is, assigned grades were closely related to performance after outplanting. As the fertility of nursery soils was increased, however, seedling morphological characteristics were altered and grading results became inconsistent. Wakeley (1954) attributed these inconsistent results to changes in the seedling's "physiological qualities" that he was unable to clarify and identify. He readily accepted the fact that changes in nursery technology were responsible, for varied performance of the morphological grades. He clearly showed that as nursery practices improved, internal physiological factors affected seedling growth and survival much more than did the morphological grades.

Nursery technology continued to improve, as did the quality of seedlots. As a result, nurseries produced seedlings that were substantially larger than the original Wakeley (1954) grade 1 and 2 seedlings. Excessive size and size variation made grading of seedlings impractical. Eventually, tops and roots were pruned in most nurseries to obtain seedlings of uniform size and seedling numbers were estimated by weighing lots rather than by counting. These mechanical manipulations, coupled with improved fertility regimes and better chemical protection, produced seedlings of uniform appearance.

As one reads chapters 6 thru 12 of the Southern Pine Nursery Handbook (1984), one can become confused about what constitutes a high-quality seedling. Nurserymen became convinced that a particular size implied high seedling quality. The original criteria were Wakeley's morphological grades. It was assumed that seedlings within prescribed limits of size and development would have high quality. The physiological quality of a seedling, however, is the ability of the seedling to survive and grow under natural environmental conditions, i.e., its fitness for outplanting. Unfortunately, the way in which seedlings are now grown makes RCD and height poor measures of fitness for outplanting.

Several years ago we began research with the Georgia Forestry Commission to determine whether first-order lateral root (FOLR) development was inherited among progeny from different mother tree selections that were established in seed orchards. According to what had been reported with sweetgum (Kormanik 1986), we thought it might be possible to develop a grading system for loblolly pine based on FOLR development. The solution was lengthy and complex, but the resulting concept is simple. Further, this concept is being applied by the Georgia Forestry Commission. In this paper, we will not address physiological, biochemical and genetic complexities of seedling development. We will simply describe nutritional and watering prescriptions for the production of loblolly pine seedlings of desired size and quality.

The History

In 1984, the initial exploratory research on frequency distributions of loblolly pine seedling by FOLR numbers was done with a mixed seedlot. The seedlings were grown in a State nursery and top-clipped two times to regulate height growth as has been done'in many nurseries. Height and RCD, although not recorded at the time, were typical for mixed loblolly pine seedlots. Heights were well within the target size for that particular nursery and the range in

RCD was acceptable. FOLR development, however, was not as uniform as one would expect based upon stem morphological characteristics.

The following year we obtained sufficient open-pollinated half-sib seeds from four mother trees from the Georgia Forestry Commission to put in a small study to determine the range in FOLR numbers. We grew the seedlings with essentially the same nutritional regime then used.by the Georgia Forestry Commission and most other State nurseries. The only production practice we omitted was top clipping. We left the seedling tops intact because we wanted to retain natural balance between roots and tops. The majority of seedlings ended up 45 to 70 cm tall instead of the desired 25 to 35 cm. The RCD range was greater than expected, 1.5 to 14 mm, even within the same half-sib seedlot. In December, top:root ratios of 8:1 were the rule. Survival percentages in an outplanting of these seedlings were over 80 percent during the drought year of 1986. Realistically, however, the seedlings were too large to be readily planted by hand or machine.

Morphological characteristics of these seedlings were revealing. Seedlings with the fewest number of matured and suberized FOLR were below the main seedling canopy level, had succulent stems, had few mature needle fascicles, and lacked terminal buds. These were identical to the undesirable traits described by Wakeley (1954). Wakeley's poor grade 3 seedlings, grown under early nursery technology, were less than 13 cm tall and had diameters of <3.0 mm. It was readily apparent that the fertilization rates, without clipping, were far too high to produce seedlings of target size.

In 1986 we began cooperative research on the genetic aspects of FOLR development of progeny of loblolly pine mother trees in Georgia Forestry Commission seed orchards. To better control seedling sizes in this study, nitrogen applications were reduced by one-third to 56 kg/ha per application. The target soil concentrations of phosphorus and potassium were reduced from 125 ppm (Bray II and available K) to 75 and 80 ppm, respectively. These levels were comparable to those we used for sweetgum (Kormanik 1986). No top clipping was imposed in this study.

The reductions in soil fertility decreased seedling heights by 10 to 15 percent, but the diameter distribution was compressed with few seedlings exceeding 9 mm (Kormanik et al 1990). Again, as in the early exploratory work, those seedlings which were unable to compete successfully in the nursery at bed densities of $280/m^2$ had all the undesirable characteristics of Wakeley grade 3 seedlings and they possessed less than 4 FOLR. Although, the seedlings we grew were too large for convenient machine or dibble-bar planting, survival of the ones we did plant was acceptable, > 80 percent for most of the 12 families. This survival was obtained &ring the severe drought that continued into 1987. A mechanical planter was specially adapted for the large seedlings. It probably would not have been practical had the planting site contained a higher percentage of clay.

During the 1986 growing season we had periodically lifted seedlings to follow FOLR development. Root development proceeded slowly from May through late July, whereas tops developed rapidly as soon as mature needle fascicles developed. With limited root development for such an extended period, most of the N applied at 56 kg/ha probably was not utilized by the developing seedlings and may have ended up contributing to nitrate problems in the ground water.

In 1987, the Georgia Forestry Commission began putting our initial findings into practice at their two operating nurseries, the Walker/Page complex near Reidsville and the Morgan Nursery in Byron. At this point, top clipping was continued, if needed, except for those seedlings used directly for comparison. The same protocol was followed for nutrient, requirements, but special steps were taken to reduce high levels of available soil phosphorus and to bring the other basic nutrients into some reasonable ratios for the different fields. Tensimeters were installed in all fields and research beds to monitor available water at depths of 15 and 30 cms. These tensimeters proved valuable in water regulation since the soils varied widely in clay content and water holding capacity.

We maintained the same levels of soil fertility in our experimental nursery beds in 1987 as we used in 1986 but further reduced total N applied from 224 kg/ha to 148 kg/ha. We applied 18 kg/ha in the first two applications and 56 kg/ha in the last two applications. We applied no N after mid-July in order to discourage excessive height growth after secondary needles matured toward the end of June. The results, however, were discouraging. Even with the reduced N rates, the non-clipped seedlings were as large as the 1986 seedlings. We felt that the reason for excessive height growth in 1987 was several heavy rain storms each week in late May and through most of June. Water and presumably dissolved N resulted in luxurious top growth.

We continued to lift seedlings throughout the growing season in 1987 to follow root development and observed distinctive seasonal growth patterns for roots and tops. Toward the end of September, when root growth began to increase rapidly, the top:root ratios were extremely unbalanced at 8:1. Within 30 to 45 days, the ratios were reduced to approximately 4:1 or 3:1. Much of the root growth before September was in the form of feeder roots and mycorrhizae, which were lost in lifting and not shown in the measured top/root ratio. Again, the reduced fertilizer and N rates had little effect on seedling development and the average size was almost identical to those of the previous 2 years.

We were convinced that our primary problem was excessive top growth in early spring and summer. In a small scale test, we found that we could further reduce soil fertility and increase height growth significantly by simply watering more frequently. We found, however, that this treatment did not increase diameter growth and that root development was adversely affected.

In 1988 we began to biochemically investigate why roots and tops reacted as we had observed. We regulated both the timing and amount of N and irrigation in our experimental nursery. After germination and establishment, we would only water by tensimeter readings and not by some preconceived notion of when the seedlings needed supplementary water. These experiments led to the prescription described below.

## Prescription for Growing Loblolly Pine According to Seedling Carbon Metabolism

We will describe a procedure for growing loblolly pine seedlings that is considerably different from current procedures. We think it is a good idea for several reasons:

1. Excessive soil fertility and watering are producing seedlings that must be clipped and pruned for outplanting

2. Survival in outplantings often is not satisfactory because inherently inferior seedlings are being nurtured to plantable size in nurseries. These seedlings must be grown in ways that make their inferiority obvious so they can be culled.

3. Fertilizers are being wasted and they are contaminating groundwater.

With these thoughts in mind, nursery superintendents can appreciate the need for change. They must get on board because they are the critical people for instituting change. We do not mean that the whole procedure for growing loblolly pine seedlings must be redesigned, but the changes are large, and more effort will be required. Emphasis should be on specific fields or beds, and some compromises will be needed. Regulating water is as important as regulating plant nutrition if one is to control the growth of seedlings.

(1) In the Georgia nurseries with seedling bed densities of 258 to $280/m^2$, the goal is to produce shippable seedlings 25 to 35 cm in height and $\geq$3.0 mm in RCD. Seedlings with $\leq$4 FOLR that are consistently smaller, have predominantly primary needles, and lack a terminal bud should be culled. Experiences over the past 5 years show that the seedling crop must be between 15 to 20 cm tall in mid-July, when they are "laid by." If seedlings reach this size too early, they will have *more* needle fascicles that contribute to top growth and control of subsequent height growth will be difficult. Excessive early season height growth is a major reason why top clipping has been prescribed in the past.

(2) If initial soil nutrient concentrations are high, it will take several years to equilibrate the soils in a given nursery. The available P (Bray II) should be standardized at 75 ppm. Available K should be from 80 to 100 ppm depending on the soil texture. Magnesium should be at 40 to 50 ppm and calcium at 250 to 350 ppm. The Mg:Ca ratio should be about 1:10. The pH should range between 5.2 and 5.8. Zinc and copper targets are between 30 and 8 ppm. It is important to get all fields in the nursery at comparable fertility levels. The only variables left then will be water and N.

(3) Nitrogen control is complicated by the fact that the sowing date for 60-day stratified seeds may vary by 30 days or more between years and by 14 to 20 days in any given year because of weather factors. It therefore is almost impossible to prescribe when N application should begin and how often it should be applied. Our initial 10 to 12 kg/ha N application should be made when the elongating stems above the cotleydons are between 2.5 and 3.5 cm long. At this time the root system is just beginning to develop and mycorrhizae is becoming established. This first application is usually given toward the end of May or early June. A second equal application should be made 10 to 14 days later. The next three applications should be at rates of 20 to 24 kg/ha. If rain is frequent, however, the seedlings may start to elongate rapidly and any of these N applications can be reduced or skipped.

The important point is that by mid-July seedling heights should be 15 to 20 cm. Up to and including the final mid-July N application, about 90 kg/ha of N are needed to get the seedlings into the desirable target range. In one Stormy spring season (1988), only 55 to 60 kg/ha N were needed. In a dry year (1991) almost 100 kg/ha were needed by mid-July. At this time, the taproot of most seedlings at a depth of 15 to 20 cm is $\leq 1$ mm and the FOLR are beginning to have well developed feeder roots that have visible mycorrhizae.

Between mid-August and mid-September, 90 percent or more of the seedlings will produce a well developed terminal bud. In mid-September, root development, which has lagged behind top growth, accelerates and the mycorrhizae become a conspicuous part of the developing feeder root complex. From 20 to 40 kg/ha of N should be applied at this time to encourage RCD and root growth. The beds should be undercut at 20 cm and well watered to prevent top damage. In 5 years, these September N rates have never resulted in bud breakage before mid-March, not even in 1990-91 and 1991-92 lifting seasons which were especially warm.

(4) Water has 'a significant impact on seedling development. After the fertility baseline is achieved, the major cause for variation in seedling development is water availability. Between germination and the first N application, the young succulent plants should not be subjected to any moisture stress. Initially, the beds should be watered daily to assure good germination and establishment. Up to the time the seedlings are 15 to 20 cm tall, the beds may be watered when tensimeters at 20 cm read 30 to 40 centibars. After the final mid-July N application, watering is needed only when the readings reach 70 centibars. More frequent watering or keeping moisture close to field capacity will result in rapid stem elongation that only top clipping or severe undercutting can reverse.

## CONCLUSIONS

The nursery protocol we have developed for producing loblolly pine seedlings of good quality requires close observation of seedling development and prompt decision making based on seedling growth and on environmental conditions. Timing and rate of irrigation and N application during the first 3 to 4 months after sowing are critical so that neither water nor fertilizer will be wasted. At lifting, the genetically noncompetitive seedlings are easy to identify with such morphologial traits as fewer than 4 FOLR, succulent stems, fewer needle fascicles, and absence of well-developed terminal buds. Seedlings produced with this controlled baseline fertility and watering concept stay within the size range for machine planting without being top clipped.

## LITERATURE CITED

Kormanik, P.P. 1986. Lateral root morphology as an expression of sweetgum seedling quality. For. Sci. 32:595-604.

Kormanik, P.P., J.L. Ruehle and H.D. Muse. 1990. Frequency distribution and heritability of first-order lateral roots in loblolly pine seedlings. For. Sci. 36:802-814.

USDA Forest Service. 1985. Southern pine nursery handbook. U.S. Dep. of Agric. For. Serv., Southern Region Cooperative Forestry, Atlanta, GA.

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