NITROGEN LEVELS,TOP PRUNING, AND LIFTING DATE AFFECT NURSERY DEVELOPMENT AND EARLY FIELD PERFORMANCE OF LOBLOLLY PINE SEEDLINGS'

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ABSTRACT-Loblolly pine seedling nursery development and 3-year field performance were contrasted between two nitrogen (N) application regimes and comparable top pruning regimes. Other initial soil nutritional elements were comparable, but high N seedlings received 150 lb/acre N (as NH_4NO_3) and low N seedlings received half this amount. Seedlings were either not top pruned, top pruned in August, or top pruned in August and September. The seedlings were outplanted during 12 squally spaced planting periods from mid-October to mid-March. The high N nursery seedlings were taller and had larger root-collar diameters as compared to the low N seedlings, but the latter survived and grew better after outplanting. Survival was 100 percent for the low N seedlings regardless of pruning treatment but did not reach acceptable levels for the high N seedlings until late December. The low N seedlings were consistently taller after three growing seasons and, depending on planting period, had consistently larger diameter at breast height (early planting periods) or had comparable diameter at breast height (later planting periods) compared to high N seedlings.

INTRODUCTION

Nursery technology has advanced considerably since the latter 1940's and early 1950's when extensive southern pine regeneration programs were rapidly developed to rectify regeneration shortfalls (Wakeley 1954). The most significant improvements have been those involving fertility practices. Today, a nursery is seldom faced with the problem of producing undersized seedlings. Current questions generally focus on ideal seedling size and the best nursery practice to achieve this size. There usually is not a consensus of which nursery procedures to follow. Forestry nurseries have come a long way since Boyer and South (1988) reported that 50 percent of the sampled nurseries in the South produced fewer than 5 percent grade 1 seedlings, based on Wakeley's (1954) morphological standard established at least 50 years earlier. These standards were developed when bed densities greatly exceeded those now recommended, and organic amendments instead of inorganic fertilizers were the rule. Effective irrigation systems had not yet been developed.

"Quality seedling" is a term difficult to define and is of limited value in describing the potential competitive ability of loblolly pine seedlings. Any number of nurseries have their own quality standards which serve their individual needs. Rose and others (1990) describe the attributes of loblolly pine target seedlings (i.e., quality seedlings) as those characteristics shown to affect survival and subsequent development after outplanting. When the target seedling size is exceeded, a root system may develop which can be too large to plant properly.

Our interest in nursery research was stimulated when we began intensive long-term research into the morphology and physiology of loblolly pine seedling root systems. It became apparent that a nursery fertility protocol was needed for statistically comparing results among and within loblolly pine half-sib seedlots for different years and locations. This protocol was to have a significant genetic component and thus, it was not prudent to use mechanical means to regulate or alter seedling development.

As the protocol was being developed, it became evident that commonly used nitrogen application rates and schedules made top pruning essential to maintain reasonable seedling sizes. This procedure made it difficult to obtain valid statistical comparisons when heritability estimates were calculated from specific morphological attributes from individual families' progeny. Eventually we dispensed with top pruning by development of a protocol involving significant alteration of our nitrogen application schedule. This nursery fertility protocol reported here was developed in cooperation with the Georgia Forestry Commission and many aspects of its development have been previously reported (Kormanik and Ruehle 1989; Kormanik and others 1989, 1990, 1992, 1998; Sung and others 1993a, 1993b, 1994, 1997). This protocol involved minimal mechanical manipulation of seedlings. Mechanical manipulation is used mainly to compensate for specific environmental occurrences such as frequent thunderstorms. For practical application of this new protocol, we felt it was essential to compare field performance of the seedlings grown under our nursery protocol with those produced by more traditional nursery management protocols (May 1984a, 1984b, 1984c).

Thus, the objective of this research was to compare survival and growth of seedlings in the nursery and after outplanting from a mixed loblolly pine seedlot when grown under the traditional or our nursery fertility protocols.

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METHODS

A single, mixed loblolly pine Piedmont seedlot obtained from the Georgia Forestry Commission was used in this study. The seedlings were sown in mid-April at the Institute for Tree/Root Biology (ITRB), USDA Forest Service's experimental nursery located on the University of Georgia's Whitehall Experimental Forest.

One phase of the study was designated as "Long-Term Study" (LTS) while the second phase was designated as "Dig Up study" (DUS). The LTS seedlings grown under the traditional nursery fertility protocol will be followed after outplanting until harvestable size. No designation was made as to the nature of the final crop or the rotation age specified. These seedlings were grown with nursery fertility levels comparable to that used in many nurseries during the 1980's. A seedling bed density of 24 to 26 per sq. ft. (260 to 280 per m^2) was established (May 1984c). These seedlings were irrigated as needed and total nitrogen levels of approximately 150 lb per acre N (168 kg per ha N) as NH_4NO_3 was used throughout the growing season. One-third of these seedlings were top pruned in early August and then again in mid-September, a normal procedure followed in many nurseries at that time. A like number of seedlings was pruned only once during the early August pruning. The remaining seedlings were not pruned but were permitted to grow without mechanical regulation.

The DUS seedling beds were given comparable preplant fertilizer applications but the irrigation schedule and nitrogen application rates approximated the amounts used in developing the nursery protocol employed by the Georgia Forestry Commission. In this particular growing season, approximately 75 lb per acre of N (84 kg per ha of N) (as NH_4NO_3) was applied. The amounts applied before mid-July were adjusted to obtain seedling heights of 6 to 8 inches (15 to 20 cm) at that time. Both the DUS and LTS seedlings were given an identical mid-September nitrogen top dressing of 20 lb per acre of N (22 kg per ha N)(as NH_4NO_3).

Adjacent plantation locations were prepared during the summer for DUS and LTS seedlings at the Savannah River Natural Resource Management and Research Institute maintained by the USDA Forest Service in conjunction with the Department of Energy, Aiken, SC. Thirty-six hundred planting positions were established for the LTS seedlings. This was to accommodate 12 planting dates of 100 seedlings from each of the 3 nursery treatments. Outplanting was to be undertaken to encompass the entire planting season from mid-October 1989 to mid-March 1990. The spacing was 10 by 10 feet (3.2 by 3.2 m) and the individual trees were shovel planted to maintain as much of the roots as possible. The specific planting position for each lifting date and nursery treatment was randomly assigned.

The DUS was concurrently outplanted in an adjacent area that had received identical summer site preparation. However, because these seedlings were initially designated to be excavated periodically from mid-June though the following winter for detailed root morphological and physiological evaluations, a different outplanting procedure was used to facilitate periodic seedling harvest. Fifty seedlings from each treatment were established in rows with 2 feet by 4 feet (0.61 by 1.21 m) spacing for each of 12 lifting periods. A total of 1,800 DUS seedlings were outplanted simultaneously with the LTS seedlings.

All seedling root-collar diameters (mm) and heights (cm) were recorded when seedlings were lifted and root systems were evaluated. Seedlings that were damaged in lifting or which had mainly primary needles were culled before outplanting. This closely approximated characteristics of seedlings being shipped from commercial nurseries and removed only 5 to 10 percent of the seedlings.

Statistical Methods

The LTS phase was a statistically designed study consisting of a factorial treatment combination of 3 pruning and 12 planting periods. Replication consists of 100 trees per treatment with each tree arranged in a completely randomized design over the 3,600 planting positions. Thus, traditional analysis of variance and mean separation tests are planned for future analyses. The DUS was installed as a demonstration study since field logistics prevented a valid statistical design. Each of the three nursery pruning treatments at a given planting period was arranged systematically down a length of planting row. Each planting period and pruning treatment combination had 50 trees. No statistical tests were valid so only treatment means were compiled and used to compare trends over the 12 planting periods and the 3 pruning treatments. Since the effect of low (DUS) and high (LTS) nitrogen was investigated in separate phases, there also were no valid statistical comparisons between N levels. Instead, relationships between nitrogen levels were compared with means which were used to evaluate trends over time. These relationships were developed by formulating linear regression equations which took into account variations in the biweekly data and extracted meaningful trends.

RESULTS AND DISCUSSION

Due to budget restrictions and personnel limitations, the DUS seedlings were never excavated as scheduled at the Savannah River Plant site. The plantation was not visited again until the seedlings had completed their third growing season in 1992. At that time, the DUS seedlings were experiencing competition between rows as well as within rows. Seedling development had not yet been hampered by the close spacing but any future data would be highly suspect due to developing lateral root competition. The LTS seedlings were not experiencing any stem or root competition and long-term measurement and observations are continuing. Early results have been recently reported (Kormanik and others 1998).

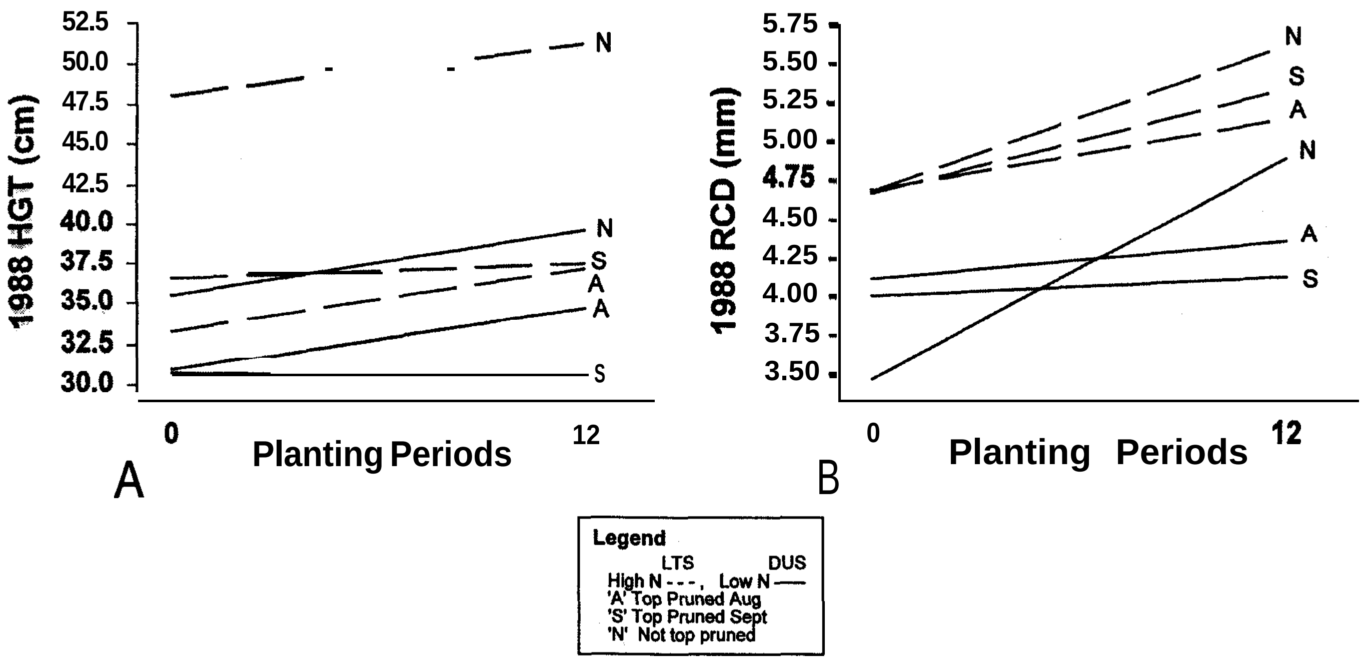
Most reports regarding top-pruned seedlings contrast seedling development under a single uniform nutritional treatment which uses various mechanical means for regulating a seedling's morphological characteristics. Usually one fertility treatment is not optimal for all mechanical seedling regulatory regimes for seedlings since the larger, unpruned seedlings would normally have the least desirable top/root ratio. This can result in lower survival after outplanting. The research reported here differed in that it used uniform mechanical treatments to regulate seedling development but varied the nutritional protocol in order to compare how nursery practices affect early plantation performance. Most nurseries in the South depend heavily on mechanical means to regulate loblolly seedling sizes (South 1994). However, it is generally accepted, and this research substantiates, that top and root pruning is used in excess to correct growth imbalances of loblolly pine caused by suboptimal nursery management practices (Mexal and Fisher 1984).

Nursery Development

It is well known that loblolly pine seedlings follow a rather precise ontogenetical development sequence between root and stem activity (Wakeley 1954). Both nursery N treatments followed this reported pattern even though actual seedling sizes varied. The DUS seedlings produced with our nursery protocol reached the desired height of 6 to 6 inches (15 to 20 cm) by the middle of July, when secondary needle development commences. The LTS seedlings attained this size several weeks earlier. This size can occur as early as mid-June as a result of over zealous fertilization and irrigation. Thus, seedling size and secondary needle formation are a function of fertility more than an age response (Kormanik and others 1992). However, early development of secondary needles has little effect on root system activity. As Wakeley (1954) demonstrated, it is mid-August before root activity and root growth begins to be a major sink for carbohydrates (Sung and others 1993a,1994).

This research demonstrates that high application rates of nitrogen early in the growing season results in excessive stem elongation, which results in unbalanced top/root ratios that require top pruning to rectify. Figure 1 presents nursery data for the DUS and LTS seedlings, showing the effects of seedling nutritional protocols and top pruning on seedling development for the 12 outplanting dates. The LTS unpruned seedling stem heights were much taller than all other treatments regardless of N level. RCD was similar among the high N treatments (figs. 1 a and 1 b). This has been reported elsewhere and is the underlying reason for employing top pruning to readjust top/root ratios to achieve improvement in seedling survival and early field performance (Kormanik and others 1994, Mexal and Fisher 1984). Note in figure 1 a that except for the unpruned LTS individuals, all other seedlings are well clustered within a few centimeters of the 30 to 32 cm upper target height commonly desired for artificial regeneration. The same response has been reported among half-sib progeny from specific mother trees that had been grown under different N regimes (Kormanik and others 1994). The RCD's are consistently larger in LTS seedlings regardless of pruning treatment. This would presumably have positive effects on early survival and height growth (fig. 1 b).

Interestingly, when nutritional analyses are reported for seedling components, especially nitrogen, the analyses are reported for the seedling at harvest. It is thus assumed that high levels of nitrogen are required throughout the summer to attain and maintain these levels. In fact, this experiment suggests that much N input is directed to wound recovery resulting from mechanical regulation of seedlings. Such input is not required to maintain a specific elevated N level. This latter conclusion is substantiated by a recent report by Sung and others (1997). They report that when only 96 lb per acre N (108 kg per ha N) are applied to loblolly pine seedlings from May to September, N content of loblolly seedlings were within desirable N levels at harvest (May 1984a).



Figures la and lb-Initial heights (HGT) and root-collar diameters (RCD), respectively, of loblolly pine seedlings produced in nursery with and without top pruning at 2 nitrogen levels and lifted on 12 different dates.

The nursery philosophy espoused by this protocol is not to waste nitrogen and contribute excessively to ground water nitrate contamination (Kormanik and others 1992). The goal is to produce a seedling that is balanced nutritionally and morphologically, taking advantage of a species' natural ontogenetic development. We direct management inputs into growing the best naturally balanced seedlings that are economic to grow and plant, have good survival, and exhibit good field performance. This approach may prevent unwarranted levels of N application that are leading many to advocate severe nitrogen use restrictions. These restrictions may complicate N use in many cropping systems including forest seedling nurseries (Johnson 1991).

Field Observations

While the nursery research produced no unexpected results, the field performance for both survival and growth contradicted what commonly has been accepted as factual. This has significantly and positively impacted further development of the nursery protocol with the cooperation of the Georgia Forestry Commission.

Survival

Perhaps the most unexpected field response was that obtained for survival (fig. 2). Here, the larger LTS seedlings, regardless of pruning treatment, did not exhibit acceptable survival percentages until the 6th or 7th planting period, which occurred in January. The nonpruned LTS seedling survival percentages ranged from 36 and 62 percent throughout the first six planting dates. The pruned LTS seedlings had comparable survival rates among planting periods and varied between 56 to 80 percent (fig. 2). The survival percentage for the DUS individuals grown under our nursery protocol was 100 percent regardless of nursery pruning regime (fig. 2). This loo-percent survival of the DUS seedlings was unexpected because in many previous trials survival has consistently fallen between 75 to 90 percent, depending upon environmental and edaphic conditions on

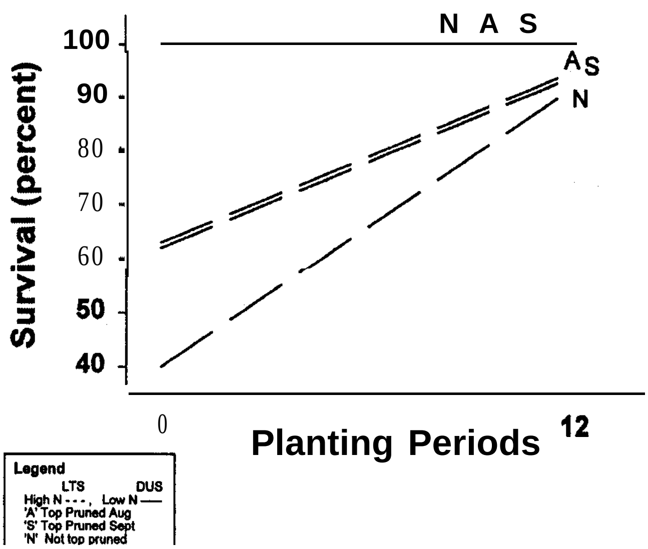


Figure 2-Third-year survival of loblolly pine seedling with and without top pruning grown at different nitrogen levels and outplanted at 12 different lifting dates.

the plantation sites. This may have just been an outstanding year for establishing plantations. On the other hand, both groups of seedlings were exposed to identical field conditions.

Initially, the low survival of the LTS seedlings was of considerable concern to us but a review of the literature indicates that the survival rates we observed are typical. In a southwide study, including 20 nursery locations where foliar nitrogen content was investigated, Larsen and others (1988) reported first-year survival of 65 percent. The seedlings were from a single sampling period from early to mid-December, which is considered to be near optimal for plantation establishment in many areas, and is comparable to our 6th and 7th planting periods. Comparable survival percentages of 60 to 75 percent have been reported in Texas for 1987-95 (Barber 1996).

In the 1987 Conservation Review Plan for the Southern Region, the survival for the 1986-87 planting season ranged from 60 to 76 percent with an overall average of 71 percent. In Matney and Hodges (1991) review, they report a survival percentage of 55 to 90 percent over a 16-year period with an average survival of 73 percent. Interestingly in only 3 of these 16 years did survival exceed 80 percent. Thus, the overall survival of the LTS seedlings obtained here might not be uncommon since data from many reports may represent seedlings lifted during one optimal period. Sung and others' (1994) research clearly demonstrates how clipping may alter carbon allocation from a developing root system to wound response and affect seedling survival.

Growth Observations

Survival is but one important factor that must be considered in judging a seedling's competitive potential. Survival and subsequent growth are not always comparable. Frequently, smaller seedlings survive better but larger seedlings normally grow better (Thompson 1985). This did not occur here as the smaller, well-balanced seedlings both survived and grew better than the larger and presumable morphological improved seedling obtained through high fertilization and top pruning.

It is apparent (figs. 3a and 36) that the initially smaller but better balanced DUS seedlings were consistently better field performers for height growth regardless of nursery pruning treatments or nitrogen application schedules. It is unfortunate that the close spacing of the DUS seedlings prevented long-term comparisons with the LTS seedlings. We installed the study with the wrong assumption, i.e., that large, heavily fertilized seedlings are best for maximum competition potential.

The LTS seedlings were most difficult to plant properly even with shovel planting. It is unlikely that such large pine seedlings would consistently be planted properly and, thus, their long-term performance might be questionable (Gruschow 1959). Many of the first-order-lateral roots (FOLR) were in excess of 2 mm in diameter and were difficult to properly place in the planting hole. For both DUS and LTS treatments, there was a reduction in height and diameter at breast height after three field growing seasons as one progressed from October to March. This is expected since it is well known that late season transplanting has adverse effects on loblolly pine seedlings. Regarding the diameter at breast height development, the late season planting periods were undesirable for all nursery treatments. Recently Sung and others (1994) reported the biological basis of late season growth depression is due to a post transplant shock that severely restricts root function. This shock may extend for 60 to 90 days. The extended post transplant shock extends well into late spring and exposes the late season planted seedling to excessive stress due to unfavorable weather conditions before the roots are fully functional.

CONCLUSIONS

(1) Once target seedling size is determined, it may be better to take advantage of natural ontogenetic development than to rely upon mechanical regulation to control seedling sizes which have been fertilized to excess. Seedlings must be of appropriate sizes to be planted properly with planting techniques currently being used.

(2) Depending upon environmental conditions during the growing season, root wrenching may be occasionally required to prevent excessive stem elongation after secondary needles begin maturing.

(3) Mid-September N applied when loblolly pine root systems begin rapid expansion is beneficial and rarely causes buds to elongate on nonpruned seedlings. However, pruned trees lacking adequate terminal maturation may begin elongation more readily than the nonpruned seedlings.

(4) Although early season lifting research on storage of seedlings has not been completed, lifting and immediately planting loblolly pine seedlings under proper conditions is highly desirable and greatly expands the growing season. This early planting, however, may not be practical with excessively large morphologically improved seedlings because survival is decreased as a result of the long transplant shock period of loblolly pine.

(5) When practical, early season planting should be favored over late spring planting.

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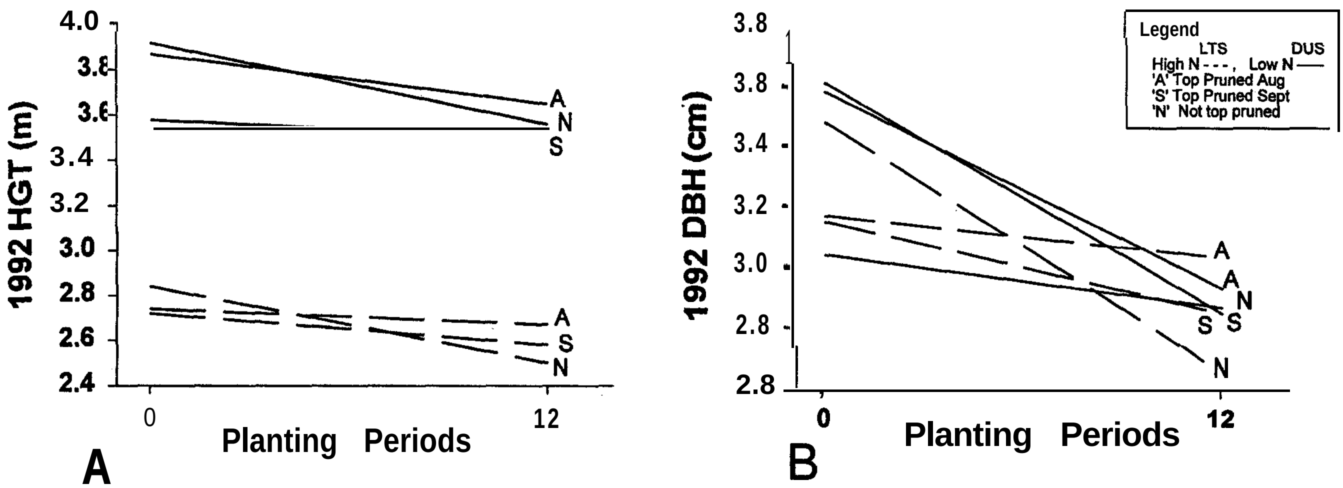

Figures 3a and 3b—Third-year heights (m) and diameter at breast height (cm), respectively, of loblolly pine produced in nursery with and without top pruning at 2 nitrogen levels and lifted on 12 different dates.

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