# DETERMINATION OF OPTIMUM SEEDLING BED DENSITY FOR BARE-ROOT HONDURAS CARIBBEAN PINE

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Abstract - The basis for determination of optimum bed density for Honduras Caribbean pine seedlings in Queensland is described. Bed densities ranging from 100 to 240 plants per sq m are evaluated for their impact on seedling quality. A culling rate at 5 per cent or less was achieved with seedling bed densities of about 160 plants per sq m or below. Cull rates under operational conditions were considerably higher than those achieved in trials, apparently due to the use of an imprecise sowing machine. Cull rates were reduced to around the trial levels when a vacuum-drum precision sower was used.

Additional keywords: Culling, nursery, sowing machine, *Pinus caribaea* var. *hondurensis*.

## INTRODUCTION

This paper reports two trials which investigate the relationship between seedling bed density and the quality of bare-root Honduras Caribbean pine (*Pinus caribaea* Mor. var. *hondurensis* Barr. et Golf.) seedlings at the time of lifting. The results of the trials have been used in the formulation of prescriptions for the nursery culture of this pine in Queensland.

The quality of seedlings at the time of lifting may be defined in terms of the eight shoot development classes described by Bacon and Hawkins (1977). These classes and their effect on field survival are listed in Table 1.

Culling to remove poorer quality seedlings (generally classes 1 and 2) is practices in Queensland where the percentage of culls at the time of lifting exceeds about 5 per cent; the operation is not considered to be economically justified where percentages fall below this figure. Since there are significant operational advantages in a cull-free handling system, the determination of sowing rates in the State's nurseries is based on the production of the maximum number of seedlings per unit area, consistent with a cull rate of less than 5 per cent.

The basis for the determination of optimum bed density for Honduras Caribbean pine seedlings in Queensland is described in this paper, together with an assessment of progress towards the goal of a less than 5 per cent cull rate in operational practice.

## MATERIALS AND METHOD

Two trials were carried out, one in 1977 and the other in 1982, at the two major southern pine nurseries in south east Queensland.

Table 1. Caribbean Pine Shoot Development Classes

| Class | Stem, Bud and Needle Characteristics | Field Survival % |
|---|---|---|
| 1 | Soft white stem bearing only primary needles. | 30 |
| 2 | Pliable stem with fascicles developing in primary leaf axils. | 55 |
| 3 | Secondary needles common, upper stem soft and immature. | 76 |
| 4 | As for Class 3 with shoot top maturing. | 80 |
| 5 | Mature plant in a resting condition with a hard lignified stem completely clothed in secondary foliage. | 78 |
| 6 | Seedling previously Class 5 now possessing a tuft of glaucous foliage on the shoot tip. | 84 |
| 7 | The new growth initiated in Class 6 has now elongated, and the flush shoot is soft and white stemmed. | 79 |
| 8 | The flush shoot of Class 7 is now maturing. | 81 |

After Bacon and Hawkins 1977

## Trial 1

This trial was sown at Beerburrum nursery (27°S) in August 1977. Honduras Caribbean pine seed was sown densely in raised beds with seven drills per bed at a spacing of 16 cm between drills. Sowing depth was 5 mm.

On completion of germination, seedlings were thinned uniformly to give bed densities of 100, 120, 140, 160, 180, 200, 220 and 229 seedlings per sq m. These treatments were arranged in a randomised complete block design comprising four replications.

Routine nursery prescriptions for fertilising, weed control and root wrenching were applied.

Superphosphate (500 kg per ha), muriate of potash (120 kg per ha) and urea formaldehyde (200 kg per ha) were applied to the beds as a pre-sowing fertilizer. An additional fertilizer application comprising potassium sulphate (150 kg per ha) and nitram (320 kg per ha) was made in November.

Beds were maintained in a weed free condition by pre- and post-emergent spray applications of chlorthal (22.4 kg per ha) plus propazine (1.1 kg per ha).

Root wrenching to a depth of 15 cm was commenced when seedlings averaged 15 cm tall. Wrenching was at monthly intervals, but was more frequent when height development was rapid. Lateral pruning commenced after the second undercut and was repeated at six weekly intervals.

## Trial 2

This trial was sown at Toolara nursery (26°S) in August 1982. Honduras Caribbean pine seed of a different batch to that used in Trial 1 was again sown densely in raised beds. In this instance each bed comprised eight drills spaced 12.5 cm apart.

After germination, seedlings were thinned to 120, 160, 200 and 240 plants per sq m. Layout consisted of four randomised complete blocks.

Fertilizing, weeding and conditioning prescriptions were similar to those described in Trial 1.

Seedlings were lifted at age 11.5 months.

## Assessments

Immediately after lifting, all seedlings were assessed for:

- shoot height (plant height from tip to root collar),
- shoot development class (after Bacon and Hawkins 1977),
- root collar diameter.

# RESULTS

## Shoot Height

Over the range of bed densities tested in Trials 1 and 2, bed density had no effect on shoot height (Table 2).

## Shoot Development Class

In both trials average shoot development class decreased with increasing bed density (Table 3).

## Root Collar Diameter

Average root collar diameter decreased with increasing bed density in both trials (Table 4).

Table 2. Average Shoot Height of Honduras Caribbean Pine Seedlings at Different Bed Densities

| Density (seedlings per sq m) | Average Shoot Height (cm) | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 100 | 35.0 | |
| 120 | 35.3 | 40.1 |
| 140 | 37.0 | |
| 160 | 36.0 | 41.7 |
| 180 | 38.5 | |
| 200 | 34.5 | 40.6 |
| 220 | 37.2 | |
| 229 | 36.4 | |
| 240 | | 40.0 |

Items within columns are not significantly different at the 1 per cent level.

Table 3. Average Shoot Development Class of Honduras Caribbean Pine Seedlings at Different Bed Densities

| Density (seedlings per sq m) | Average shoot development class | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 100 | 5.2 a | |
| 120 | 5.0 a b | 5.6 a |
| 140 | 5.1 a b | |
| 160 | 4.6 a b | 5.2 b |
| 180 | 4.8 a b | |
| 200 | 4.6 a b | 5.0 b c |
| 220 | 4.5 a b | |
| 229 | 4.3 b | |
| 240 | | 4.7 c |

Items within columns followed by the same letters are not significantly different at the 1 per cent level.

Table 4. Average Root Collar Diameter of Honduras Caribbean Pine Seedlings at Different Bed Densities

| Density (seedlings per sq m) | Average root collar diameter (mm) | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 100 | 6.8 a | |
| 120 | 6.2 a b | 6.4 a |
| 140 | 6.0 a b c | |
| 160 | 5.5 b c d | 5.9 a b |
| 180 | 5.7 b c d | |
| 200 | 5.2 b c d | 5.5 a b |
| 220 | 5.1 c d | |
| 229 | 4.9 d | |
| 240 | | 4.6 b |

Items within columns followed by the same letters are not significantly different at the 1 per cent level.

## DISCUSSION

It is apparent from the figures in Table 3 that increasing bed density results in depressed plant quality based on the classification of Bacon and Hawkins (1977). It also results in a lowering of average root collar diameter (table 4).

Following the work of Bacon and Hawkins (1977) and subsequent trials which demonstrated the poor field growth and survival of plants in shoot classes 1 and 2, the Queensland Forestry Department adopted a nominal culling technique based on the rejection of such plants as well as those with root collar diameters below 3 mm. In practice, the small diameter plants are invariably removed during the process of culling shoot classes 1 and 2.

The effect of seedling bed density on cull percentage under the above prescription is illustrated in Figure 1. The effect of bed density on the yield of plantable seedlings is also shown.

In both trials the yield of plantable seedlings rises steadily over the range of bed densities tested. The cull rate also rises steadily with increasing bed density, however, and the critical level of 5 per cent culling is reached at a bed density of around 160 plants per sq m.

Based on the results of these trials, it would be expected that the adoption of sowing rates for Honduras Caribbean pine aimed at the production of 160 plants per sq m in these nurseries should result in the production of nursery crops which require less than 5 per cent culling. Under such circumstances field managers could take advantage of the cost savings assoc-

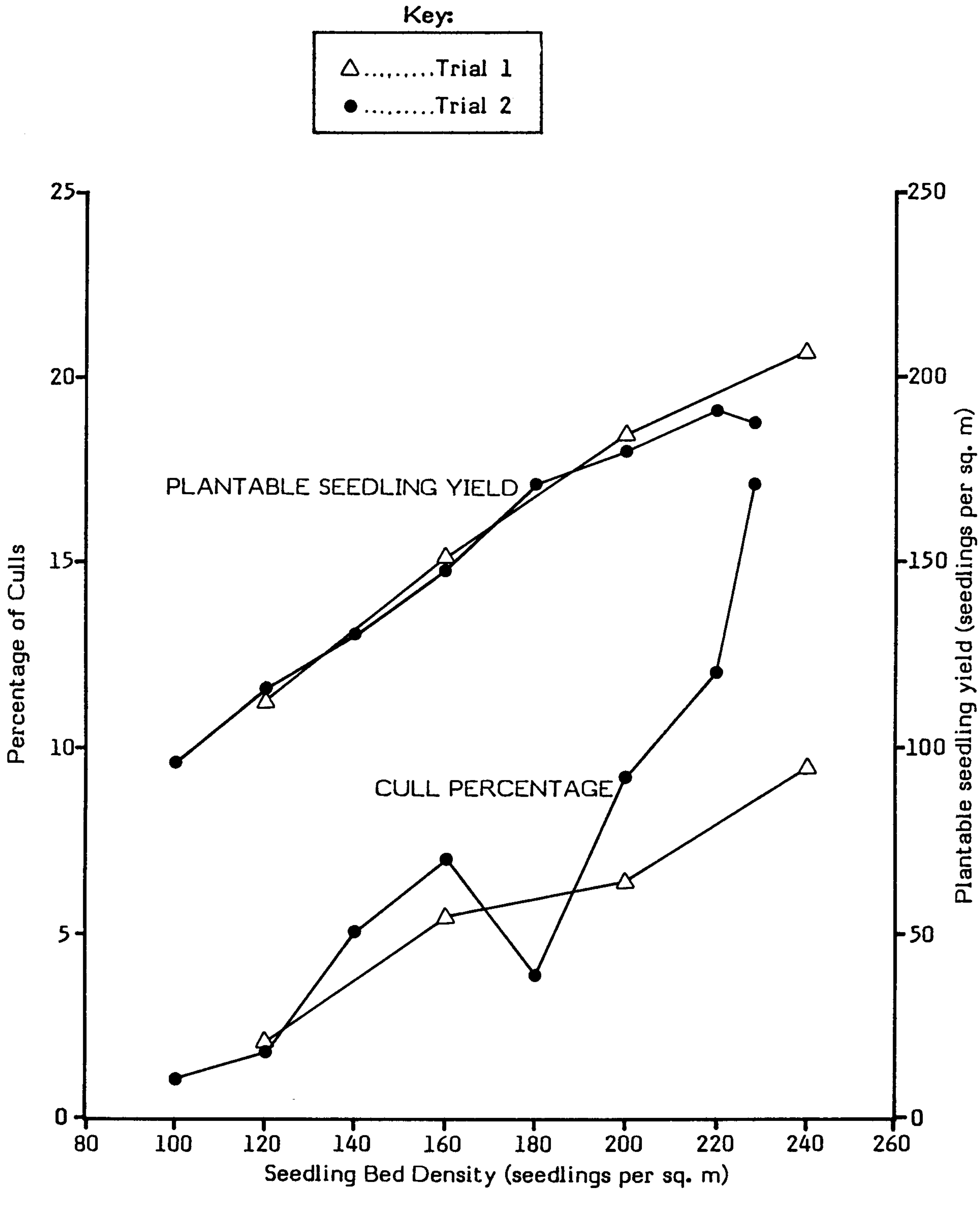


**Figure 1. Cull Percentage and Plantable Seedling Yield in relation to Seedling Bed Density for Trials 1 and 2.**

iated with a cull free handling system (Shea and Armstrong 1978).

The production objective of 160 plants per sq m for Honduras Caribbean pine was adopted in Queensland in 1978.

## OPERATIONAL PRACTICE

In spite of the fact that bed density targets were often achieved for Honduras Caribbean pine after 1978, field managers still found that culling was necessary to remove the relatively large number of poor quality class 1 and 2 seedlings which were present in the routine planting stock.

During large scale planting operations, culling takes place in the field immeditely prior to planting. The standard of plants removed may vary considerably depending on the quality of labour, scarcity of plants, standard of supervision and many other factors. In order to determine the requirement for culling in routine planting stock, a systematic sampling procedure was commenced in the Toolara nursery in 1980. Stock from one square metre bed samples was graded at the time of lifting and the cull rate was calculated for each seed batch. Average cull rates for Honduras Caribbean pine in the nursery over the 6 year period 1980 to 1985 are listed in Table 5 together with the corresponding average bed density.

Table 5. Relationship between bed density and cull rate at Toolara nursery

| Year | Sower type | Bed density /m$^2$ | Cull rate % |
|---|---|---|---|
| 1980 | Belt | 136 | 17.9 |
| 1981 | " | 137 | 12.7 |
| 1982 | " | 122 | 11.4 |
| 1983 | Vacuum | 165 | 9.0 |
| 1984 | " | 130 | 20.9* |
| 1985 | " | 160 | 4.4 |

* An unidentified disorder caused general malformation of stock.

Prior to 1983, cull rates for nursery stock were consistently higher than 10 per cent even though average bed densities were well below 160 plants per sq m. Following the introduction of a vacuum-drum sower to the Toolara nursery in 1983 there was an immediate drop in the cull rate despite an increase in bed density to around 160 plants per sq m. The high cull rate in 1984 includes the effect of a general disorder which resulted in poor apical dominance throughout the nursery. The cull rate of 4.4 per cent for the three batches of Honduras Caribbean pine (over 1 million plants) lifted to date in the 1985 planting season is the lowest recorded in the six year period.

The relationship between bed density and cull rate in 1983 and 1985 is reasonably consistent with that demonstrated the two trials reported here. The improvement in seedling quality in these two years appears to be associated with the change, in 1983, from a relatively imprecise belt sowing machine to a New Zealand made vacuum-drum precission sower. Under the trial conditions, seedling were placed very accurately and uniformly at all bed densities; the introduction of the new sowing equipment has allowed similar sowing accuracy to be achieved in practice. The belt sower, used prior to 1983, tended to place seeds irregularly along the drill, with the result that individual plants were often crowded where groups of seed were placed. Seeding competition and uneven development as a result of this crowded placement would account for the higher cull percantages prior to 1983.

Introduction of a precision sower to the Toolara nursery appears to have reduced cull rates to a level whereby, under average conditions, stock may be planted in the field without the necessity for an expensive culling operation.

## CONCLUSIONS

The intensity of culling required to remove poor quality Honduras Caribbean pine seedlings at the time of lifting increases as bed density increases in the range 100 to 240 plants per sq m. Under experimental conditions a cull rate of less than 5 per cent may be achieved where bed density is 160 plants per sq m or less. Considerably higher cull rates have been recorded under large scale operational conditions were bed density was below 160 plants per sq m and a low precision sowing machine was used. Irregularities in seed spacing along the drills may be responsible for the higher than expected cull rate.

The use of a vacuum-drum precision sower has reduced cull rates to levels approaching those obtained in experimental trials.

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Seedbed Density Affects Performance of Slash and Loblolly Pine in Georgia

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Abstract.--In four trials, seedbed density significantly affected seedling morphology in the nursery as well as survival and growth of seedlings in field plantings. Seedbed density (108 to 484/$m^2$) was negatively correlated (P=0.01) with seedling height, shoot weight, stem diameter index, root weight, large root weight, small root weight, and number of first order roots per tree at time of lifting from the seedbed. Bed density, however, was positively correlated (P=0.01) with shoot/root ratio. Increased field survival was associated with decreasing bed densities in three of four outplantings but in only one outplanting was this relationship statistically significant (P=0.05). Seedbed density was also negatively correlated (P=0.05) with tree height and basal stem diameters in each of four outplantings and negatively correlated (P=0.05) with wood volume indices ($\leq D^2H$ or the sum of basal stem diameter squared x total height of living trees) in three of four outplantings. These results suggest that the quality of slash and loblolly pine seedlings can be improved and rates of survival and growth in outplantings can be increased by growing seedlings at lower bed densities than the 300/$m^2$ currently used in most southern nurseries.

Additional keywords: *Pinus taeda*, *P. elliottii* var *elliottii*, height growth, diameter growth, root growth, survival.

Although most southern forest nurserymen sow slash (*Pinus elliottii* Engelm. var *elliottii*) and loblolly (*P. taeda* L.) pine seeds at rates needed to produce 300 seedlings per square meter (28/$ft^2$), several studies have indicated that seedling quality, plantation growth, and in some cases, survival are improved by sowing seeds at lower bed densities (Burns and Brendemuehl 1971; Harms and Langdon 1977; Mexal 1981; Shipman 1964; Shoulders 1961; Switzer and Nelson 1963). The reason given by nurserymen for continuing to sow seeds for bed densities of 300 seedlings per $m^2$ in spite of these publications is economic. They contend that producing seedlings at a bed density of 215/$m^2$ would not only increase seedbed area requirements, but would also increase the time needed to prepare seedbeds and sow the nursery, apply each pesticide spray, plow middles, irrigate, and lift. Needs for fertilizer, mulch, pesticides, and irrigation would also increase. Assuming that the cost of production would increase by 40% (equivalent to the increased seedbed area needed) and that the cost at 300/$m^2$ is \$20/M, then the cost at 215/$m^2$ would only be \$28/M. Seedling performance in outplantings would also have to increase to justify the additional cost of seedlings (\$12 investment/hectare if 1500 planted/hectare). Mexal (1981) presented statistical evidence that 200 loblolly pine seedlings/$m^2$ is the biologically optimum density in seedbeds. Shoulders (1961), concluded that for nurserymen it was economically more efficient to sow seedbeds

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at 430 seedlings/$m^2$ than at 325/$m^2$. While he appears to have considered field performance in reaching this conclusion, he did not measure growth and was more concerned about nursery efficiency than increased profits of the stand.

Field performance is the key to selection of an appropriate bed density in nurseries (Wynia and McClain 1981). Improved field performance must be obtained to economically offset the additional costs of seedling production when seedbeds are sown at low densities. Several trials in New Zealand (Bowles 1981, Balneaves 1983, Balneaves and Fredric 1983) have shown that reduced seedbed density improves seedling growth and survival in outplantings of *Pinus radiata* D. Don. Their results also indicate that the optimum density is dependent on soil type and location of the nursery.

The purpose of the present work was to determine the effects of seedbed density on the morphology and quality of slash and loblolly pine seedlings produced in the Georgia Forestry Commission's Morgan and Walker nurseries as well as to determine if seedbed density is correlated with field performance.

## METHODS

Seeds of genetically improved loblolly pine were sown at high seedbed densities in 1979, 1980, and 1981 in the Georgia Forestry Commission's Morgan Nursery near Byron. Seeds of genetically improved slash pine were sown at a high seedbed density in 1983 in Georgia Forestry Commission's Walker nursery near Reidsville. After germination was complete in late June of each year, replicate seedbed plots (2 each) were thinned to 10 percent above the desired densities (Table 2), and in August the plots were further thinned to obtain the desired densities. Seedlings were carefully lifted from each replicate plot in January or February of the year after sowing, and every 10th seedling was set aside until two groups of 25 were obtained from each plot for detailed measurements.

Seedling height, shoot weight, total root weight, large ($\geq$5.6 mm) root weight, small ($<$5.6 mm) root weight, and the number of first order roots were measured. Roots were divided into large and small classes by use of sieves after seedlings were oven dried and their small roots removed by careful hand stripping. An index of seedling diameter was calculated as units of shoot weight per unit of shoot height (g/cm), and the ratio of shoot to root was calculated from their weights (g/g).

Four replicates of 25 loblolly pine seedlings from each seedbed density were outplanted in a randomized complete block design from each of the three study years on separate sites in Baldwin County, Georgia. The slash pine seedlings were outplanted as three replicates of 50 seedlings from each seedbed density in a randomized complete block design on a site in Washington County, Georgia. Washington and Baldwin counties are contiguous. Loblolly pines were hand-planted; slash pines were machine-planted.

Survival, height, and basal stem diameters were recorded annually and an index of wood volume produced on each plot was calculated ($\Sigma D^2H$ or the sum of basal stem diameter squared x total height of living trees) (Hatchell, Berry, and Muse 1985). Correlation coefficients were calculated for the relationships between seedbed density and each parameter measured at lifting (Table 1) and between seedbed density and tree height, basal stem diameter, wood volume index and survival for each site and year of measurement in the outplantings. The relative economic value of producing seedlings at a bed density of 215/$m^2$ was compared with that for a bed density of 300/$m^2$ using the average percentage increase in wood volume (volume index) produced in all four outplantings in seedlings grown at the low (215/$m^2$) versus the high (323/$m^2$) seedbed density. A financial analysis was made to determine if an investment of $12/ha in additional seedling cost could be economically justified and the percentage increase in yield needed to offset the added cost in a 25 year pulpwood rotation was calculated. The principles behind such an analysis may be found in Fortson and Field (1979). Basic to the analysis are the equations:

$$NPV = \frac{(Y)\quad(S)}{(1 + i)^R} - (AC)\,\frac{(1 + i)^R - 1}{(i)\quad(1 + i)^R} - E$$

and $$FV = PV\,(1 + i)^R$$

where NPV = net present value, FV = future value, PV = present value, Y = harvest yield per hectare, S = expected stumpage value per hectare, i = discount rate, R = harvest age, AC = annual maintenance cost, and E = stand establishment cost.

## RESULTS AND DISCUSSION

Seedbed densities from 108 to 484 seedlings per square meter (10 to 45/$ft^2$) significantly affected all morphological measurements of seedlings lifted from the test plots in each of the study years. Since results were similar, only one year (1981, trial #3) of morphological data are detailed here (Table 1). Statistically significant differences in morphological characteristics were not found between seedlings grown at 215/$m^2$ and in those grown at 323/$m^2$ (Table 1). The high correlation coefficients (P=0.01) between seedbed density and each measured characteristic of lifted seedlings indicates the strong effects of density on seedling morphology and, consequently, on seedling physiology.

In the outplantings, the density at which seedlings were grown in the nursery seedbed significantly affected their height (Table 2), basal stem diameter (Table 3), wood volume index (Table 4), and survival on three of the four sites (Table 5). Seedbed density was significantly correlated with tree height (Table 2) and basal stem diameter (Table 3) in all four outplantings. It was correlated with wood volume indices (Table 4) in three and with survival (Table 5) in only one outplanting. Comparing the performance of seedlings grown at 215/$m^2$ with those grown at 323/$m^2$ indicates that seedlings grown at the lower density grow significant taller (Table 2), larger in diameter (Table 3), and consequently produce more wood (Table 4) than seedlings grown at the high density. An average of 30.6 percent increase in wood volume index was produced (Table 4) in the four outplantings by seedlings grown at 215/$m^2$ over those grown at 323/$m^2$, even though there were no significant differences in their size at time of outplanting (Table 1). Apparently, the seedlings grown at the density (215/$m^2$) claimed to be the biological optimum (Mexal 1981) possessed a physiological advantage. Wakeley (1954) said, "the effects of non visible characteristics within seedlings may be as important as effects of size and external form".

Perhaps a 30 percent increase in wood volume production is more than should be expected by extrapolation through a pulpwood rotation, but an increase of approximately 3.0 percent by the end of a rotation would be sufficient to offset a 40 percent increase in cost for production of the seedlings. Assuming seedlings cost $20/M when grown at 300 to 323/$m^2$ and $28/M when grown at 200 to 215/$m^2$, the cost of seedlings needed to plant a hectare (1500) would be $12 more if grown at the low than at the high density; yield at a harvest age of 25 years on a tract of site index 60 (base age 25) should be about 430.5 $m^3$ (48 cords/acre) with an expected value of $6.89/$m^3$; planting costs would be about $123.55/ha plus the cost of seedlings; annual maintenance costs would be about $6.20/ha and keeping all values in constant dollars and using a real discount rate of 8 percent, our net present value would be $213.57/ha if we planted the $20 seedlings and $201.61/ha if we planted the $28 seedlings. We would need increase yield by only $82.18/ha (=FV) to offset the additional seedling cost or the equivalent of 11.93 $m^3$ of pulpwood per hectare. An increase of 3.0% in yield would therefore, be more than enough to offset the increased seedling cost.

Thus, my studies suggest that the quality of slash and loblolly pine planting stock can be improved by growing seedlings at lower bed densities than the 300/$m^2$ density currently used in many southern nurseries. The actual monetary value that a landowner may gain by planting seedlings from seedbeds sown at low densities must wait until the end of a rotation, but results of this study are encouraging.

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Table 1.--Effects of nursery-bed density on loblolly pine seedling morphology at lifting in 1981 (trial 3) and correlation coefficients (r) between bed density and each measurement.

| Seedbed density (No./$m^2$) | Tree height (cm) | Shoot weight (g/tree) | Diameter index (g/cm) | Total root weight (g/tree) | Large root weight (g) | Small root weight (g) | 1st order roots (No./tree) | Shoot/root ratio (g/g) |
|---|---|---|---|---|---|---|---|---|
| 108 | 42.9 a | 38.4 a | 0.90 a | 13.1 a | 10.6 a | 2.5 a | 20.8 a | 2.93 f |
| 161 | 37.0 b | 26.0 b | 0.70 ab | 7.6 b | 6.1 b | 1.5 b | 18.0 b | 3.42 e |
| 215 | 35.6 bc | 21.2 c | 0.60 bc | 6.2 bc | 5.0 bc | 1.2 bc | 18.1 b | 3.42 e |
| 269 | 34.2 bcd | 20.0 c | 0.58 bc | 5.3 cd | 4.3 bc | 1.0 bc | 17.6 bc | 3.77 bc |
| 323 | 34.3 bcd | 17.6 cd | 0.51 c | 5.0 cd | 3.9 c | 1.1 bc | 17.1 bc | 3.52 de |
| 377 | 31.9 cd | 15.6 d | 0.49 cd | 4.1 de | 3.4 c | 0.7 c | 16.6 cd | 3.80 b |
| 431 | 29.2 d | 10.2 e | 0.35 d | 2.8 ef | 2.2 de | 0.6 c | 15.4 de | 3.64 cd |
| 484 | 23.0 e | 5.7 f | 0.25 e | 1.4 f | 0.9 e | 0.5 c | 14.3 e | 4.07 a |
| r | -.91** | -.94** | -.97** | -.88 ** | -.88** | -.86** | -.95** | .86** |

Column means followed by a common letter are not significantly different (P=.05) according to Duncan's Multiple Range Test. Correlation coefficients (r) followed by ** are significant values (P=0.01).

Table 2.--Effects of nursery-bed density on slash and loblolly pine seedling heights on four outplanting sites planted in four different years

| Seedbed density (No./m$^2$) | Seedling height (cm) Trial 4 slash pine 1st year data | Trial 3 loblolly pine 3rd year data | Trial 2 loblolly pine 4th year data | Trial 1 loblolly pine 5th year data |
|---|---|---|---|---|
| 108 | 44.6 a | 169.7 a | 257.8 a | 383.0 a |
| 161 | - [1/] | 164.1 b | 238.6 b | 385.0 a |
| 215 | 41.5 b | 165.0 b | 237.9 b | 378.2 b |
| 269 | - | 161.4 c | 227.7 c | 371.2 c |
| 323 | 38.6 b | 158.3 c | 216.5 d | 364.2 d |
| 377 | - | 150.0 d | - | - |
| 431 | 31.7 c | 145.2 e | - | - |
| 484 | - | 140.0 f | - | - |
| r | -98.* | -.97** | -.97 ** | -.94 * |

Column means followed by a common letter are not significantly different (P=0.05) according to Duncan's Multiple Range Test. Correlation coefficients (r) followed by an * or ** are significant values (P=0.05=*; .01=**).

[1/] A - indicates missing data because not all densities were tested in each trial.

Table 3.--Effects of nursery-bed density on basal stem diameters of slash and loblolly pine seedlings on four outplanting sites planted in four different years

| Seedbed density (No./$m^2$) | Basal stem diameters (cm) Trial 4 slash pine 1st year data | Trial 3 loblolly pine 3rd year data | Trial 2 loblolly pine 4th year data | Trial 1 loblolly pine 5th year data |
|---|---|---|---|---|
| 108 | 1.1 a | 4.4 a | 6.3 a | 5.7 a |
| 161 | - [1/] | 4.3 ab | 5.7 bc | 5.2 b |
| 215 | 1.0 a | 4.4 a | 5.7 bc | 5.2 b |
| 269 | - | 4.2 b | 5.5 cd | 5.0 c |
| 323 | 0.8 b | 4.2 b | 5.2 d | 4.9 c |
| 377 | - | 3.9 c | - | - |
| 431 | 0.5 c | 3.7 c | - | - |
| 484 | - | 3.2 d | - | - |
| r | -.98* | -.90** | -.94* | -.92* |

Column means followed by a common letter are not significantly different (P=0.05) according to Duncan's Multiple Range Test. Correlation coefficients (r) followed by an * or ** are significant values (P=0.05=*; 0.01=**)

[1/] A - indicates missing data because not all densities were tested in each trial.

Table 4.--Effects of nursery-bed density on slash and loblolly pine wood volume indices (WVI = $\Sigma D^2H$) on four sites outplanted in four different years

| Seedbed density (No./$m^2$) | WVI (thousands) Trial 4 slash pine 1st year data | Trial 3 loblolly pine 3rd year data | Trial 2 loblolly pine 4th year data | Trial 1 loblolly pine 5th year data |
|---|---|---|---|---|
| 108 | 8.0 a | 93.1 a | 266.8 a | 220.6 a |
| 161 | - [1/] | 84.1 bc | 202.5 b | 169.5 c |
| 215 | 5.6 b | 88.6 ab | 204.5 b | 198.7 b |
| 269 | - | 80.7 cd | 184.5 c | 169.2 c |
| 323 | 4.3 c | 76.0 d | 153.5 c | 139.7 d |
| 377 | - | 63.9 e | - | - |
| 431 | 3.6 d | 60.1 ef | - | - |
| 484 | - | 55.3 f | - | - |
| r | -.97* | -.97** | -.93* | -.83 |

Column means followed by a common letter are not significantly different (P=0.05) according to Duncan's Multiple Range Test. Coorelation coefficients (r) followed by an * or ** are significant values (P=0.05*; 0.01=**).

[1/] A - indicates missing data because not all densities were tested in each trial.

Table 5.--Effects of nursery-bed density on survival of slash and loblolly pine seedlings on four field sites planted in four different years

| Seedbed density (No./m$^2$) | Survival (%) Trial 4 slash pine 1st year data | Trial 3 loblolly pine 3rd year data | Trial 2 loblolly pine 4th year data | Trial 1 loblolly pine 5th year data |
|---|---|---|---|---|
| 108 | 64 a | 98 a | 96 a | 60 a |
| 161 | -[1/] | 99 a | 97 a | 59 a |
| 215 | 68 a | 99 a | 95 a | 55 b |
| 269 | - | 99 a | 94 ab | 55 b |
| 323 | 59 a | 97 a | 89 b | 45 c |
| 377 | - | 97 a | - | - |
| 431 | 45 b | 100 a | - | - |
| 484 | - | 98 a | - | - |
| r | -.85 | -.08 | -.86 | -.91* |

Column means followed by a common letter are not significantly different (P=0.05) according to Duncan's Multiple Range Test. Correlation coefficients (r) followed by * are significant values (P=0.05).

1/ A - indicates missing data because not all densities were tested in each trial.

# SEED BED DENSITY, UNDERCUTTING, AND LATERAL ROOT PRUNING EFFECTS ON LOBLOLLY SEEDLING MORPHOLOGY, FIELD SURVIVAL, AND GROWTH

Russell J. Nebgen and Joann F. Meyer

Abstract--Nine plantings (three per year for 1982, 1983, and 1984) of a nursery treatment study were installed to examine the effects of seed bed density, lateral root pruning, and undercutting on loblolly pine survival and growth.

Decreasing seed bed density from 40 to 32 to 24 seedlings per square foot significantly increased root collar diameter, root and shoot weights, and improved seedling grade, survival (by 6.1%) and growth on droughty sites. Lateral root pruning treatments had no effect on survival or growth. Undercutting twice a year (in July and September) reduced seedling size but produced a more fibrous root system that improved survival (by 4.9%) on poor survival sites. The genetically improved "drought hardy" seed source developed by the Texas Forest Service averaged 7.2% better survival than a "woods run" checklot.

Keywords: Loblolly pine, (*Pinus Taeda* L.), seed bed, density, lateral root pruning, undercut, survival, height, and caliper.

## INTRODUCTION

Plantation establishment in East Texas is sometimes difficult to achieve due to droughty soil conditions and/or sites on the western fringe of the Loblolly pine (*Pinus taeda* L.) range which are subject to periodic droughts. Seedling survival in such droughty environments is closely related to root growth during the first growing season following planting (Stone 1967). Seedlings with healthy, fibrous root systems could be expected to have better survival in such adverse conditions.

Research studies have shown that seedling morphology does affect seedling survival and growth. Shoulders (1961) reported that in moderately dry years the best field survival of loblolly and slash (*Pinus elliotli* Engelm.) pines were from trees grown in low-density beds. A similar study in South Carolina showed that with adequate moisture, survival was not affected by seed bed density (Shipman 1964). After four growing seasons, the growth differential between seedlings of low and high density beds continued to favor the seedlings grown at the lower densities (Shipman 1964).

Nursery practices which effect seedling development include seed bed density, undercutting, and lateral root pruning. Manipulating these nursery practices can favor the development of a more fibrous root system, a larger calipered stem, and a better root to shoot ratio. This study was designed to examine the effect of various applied nursery treatments on survival and growth of loblolly pine.

## MATERIALS AND METHODS

In April 1981, several nursery beds at Champion International's pine nursery near Livingston, Texas were sown with "drought hardy" loblolly pine at densities high enough to ensure a minimum of 40 surviving seedlings per square foot. These beds were hand thinned in July to 24, 32, and 40 seedlings per square foot. During the rest of the growing season two levels of lateral root pruning and undercutting were applied by nursery personnel. The two lateral root pruning treatments were: lateral pruning monthly from July to October (L1); and operationally, once in September and twice in October (L2). The last lateral prune in October was done on the outside drills only. All other lateral prunings were done on the inside drills only. The two undercutting treatments were: no undercutting (U1) and undercut in July and September (U2). These nursery treatments were repeated in 1982 and 1983.

The drought hardy seed source was from Champion International's drought hardy seed orchard located near Splendora, Texas. These genetically improved selections for drought resistance originated from the "Lost Pines" region near Bastrop, Texas and from the western edge of the species range. The control used for all locations was an operationally grown South of Highway 190 (S of 190) loblolly seedling. The south of Highway 190 refers to an area south of US Highway 190 in Southeast Texas where high quality native seed was obtained.

The study was installed at nine locations (three per year for three years) using a randomized complete block design with "drought hardy" and S of 190 seed sources. The treatments were handlifted at the nursery and then machine and hand planted in 25 tree row plots on a 1.2 x 3m (4 x 10 ft.) spacing and replicated eight times (5200 study trees per location).

The field test locations are summarized in Table 1. These locations represent droughty soil sites which were typically deep sands (locations 2, 3, 5, and 8), western fringe sites (locations 1, 4, 7, and 9), and an "average" site (location 6).

One hundred seedlings per treatment were graded each year using root collar diameter (Table 2). From this sample, 25 seedlings were oven dryed and the dry weight of the root and shoot of each seedling was measured.

Table 1. Field locations for seed bed density study in East Texas

| Location | County | Soil Description | Planting Season |
|---|---|---|---|
| 1 | Walker | Rosenwall-Goreen, fine sandy loam | 1982 |
| 2 | Polk | Susquehanna-Segno, fine sandy loam | 1982 |
| 3 | Tyler | Shanklee-Diboll, loamy fine sandy loam | 1982 |
| 4 | Houston | Diboll, very fine sandy loam | 1983 |
| 5 | Polk | Betis-Lilbert, loamy fine sand | 1983 |
| 6 | Polk | Bowie, fine sandy loam | 1983 |
| 7 | Houston | Diboll, very fine sandy loam | 1984 |
| 8 | Polk | Segno, fine sandy loam | 1984 |
| 9 | Walker | Rosenwall-Goreen, fine sandy loam | 1984 |

Table 2. Tree grading system used to evaluate seed bed density study

| Seedling Grade | #1+ | #1 | #2 | #3 | #4 |
|---|---|---|---|---|---|
| Root Collar Diameter(inches) | >¼" | >3/16-¼" | >1/8-3/16" | >1/16-1/8" | >1/16" |

The field measurements for the study included first year summer and winter survival measurements for all nine locations. The 1982 field location number one (1) failed after the first growing season. This area was re-planted as test location number nine (9) in 1984. Second year height and groundline caliper measurements were taken on the remaining two 1982 field locations and the three 1983 field locations. The data was analyzed using plot-means analysis of variance to detect any differences, and these differences were ranked by Duncan's multiple range test.

## RESULTS AND DISCUSSION

### Seedling Morphology

Decreasing seed bed density (from 40 to 32 to 24) significantly increased root collar diamter, root and shoot dry weights, and improved root/shoot ratio (Table 3). It also increased the number of Grade 1+ and Grade 1 seedlings (Figure 1).

Table 3. Duncan's multiple range test for seed bed density as it affects various seedling trait means

| Seed bed Density (seedlings/ft.$^2$) | Root Collar Diameter (inches) | Root Dry Weight (grams) | Shoot Dry Weight (grams) | Root/Shoot Ratio (dry weight) |
|---|---|---|---|---|
| 24 | .18 a [a/] | .99 a | 2.18 a | 1:2.29 a |
| 32 | .17 b | .82 b | 1.93 b | 1:2.43 b |
| 40 | .16 c | .79 b | 1.87 b | 1:2.43 b |

a/ Means with the same letter are not significantly different at alpha=0.05.

The lateral root pruning treatments did not significantly affect root collar diameter, or root/shoot ratio (Table 4). Root and shoot dry weights were increased by the monthly lateral root prunings (Table 4), but this had almost no effect on seedling grade (Figure 2).

Table 4. Duncan's multiple range test for lateral root pruning as it affects various seedling trait means

| Lateral Root Pruning | Root Collar Diameter (inches) | Root Dry Weight (grams) | Shoot Dry Weight (grams) | Root/Shoot Ratio (dry weight) |
|---|---|---|---|---|
| L1- (monthly from July to October) | .17 a [a/] | .92 a | 2.07 a | 1:2.38 a |
| L2- (once in September, once in October) | .17 a | .82 b | 1.91 b | 1:2.38 a |

a/ Means with the same letter are not significantly different at alpha=0.05.

The undercutting treatment did influence seedling morphology (Table 5). Those seedlings which were undercut twice (U2) had smaller root collar diameters, smaller shoot dry weights, and a better root/shoot ratio. The seedlings which were undercut

Figure 1. The effects of Seedbed Density on seedling caliper grade averaged across three years (1982, 1983, 1984).

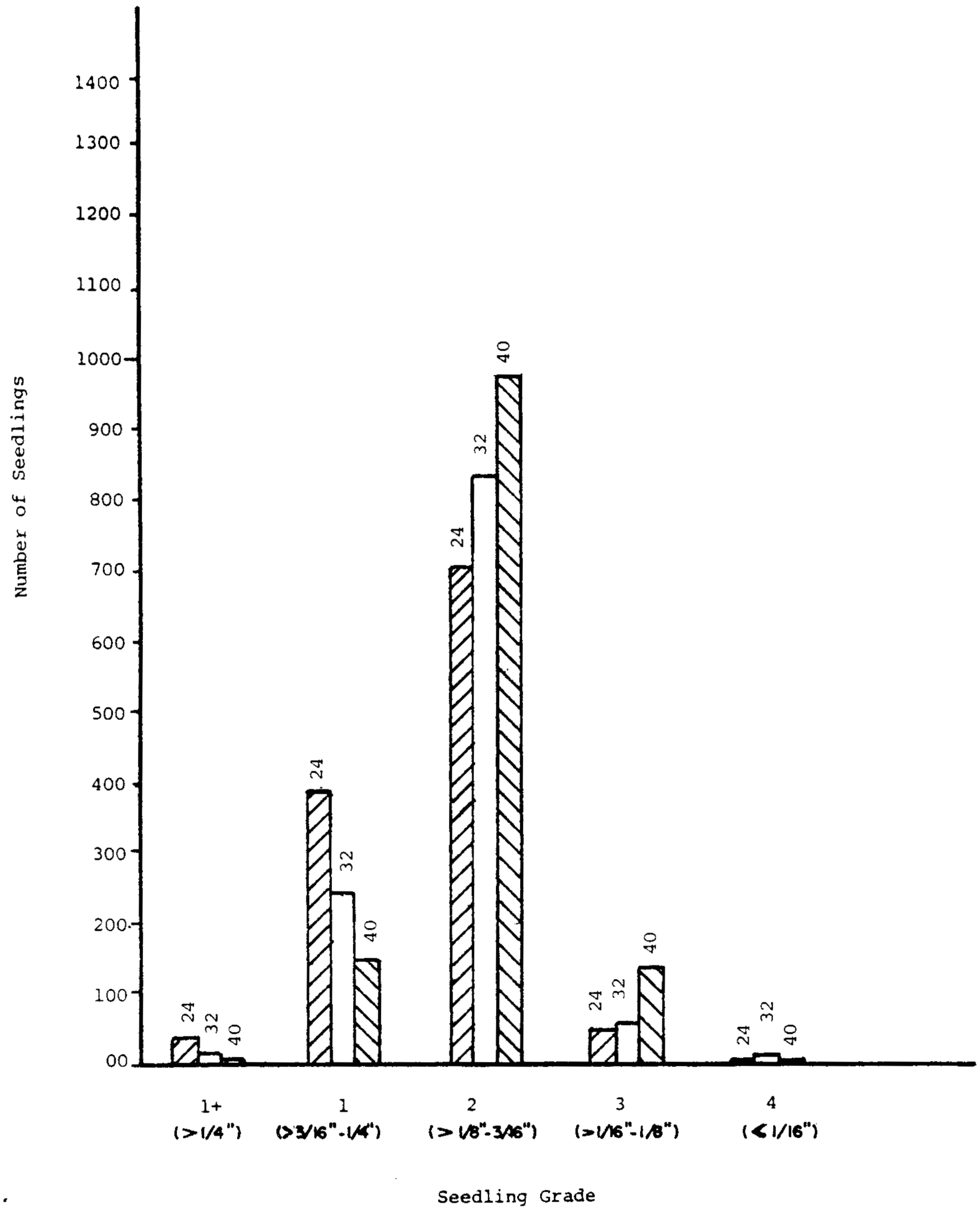
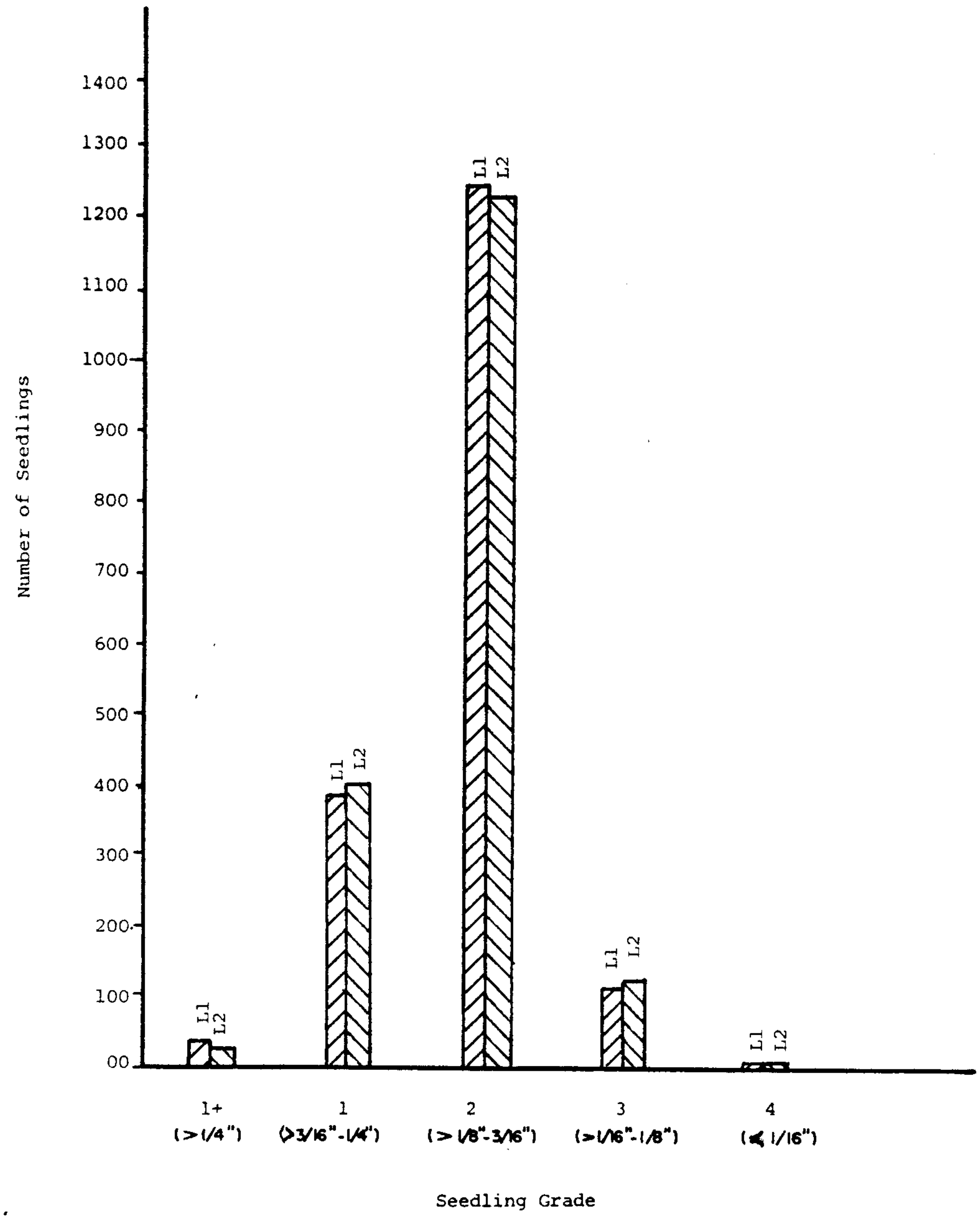


Figure 2. The effects of lateral root pruning on seedling caliper grade averaged across three years (1982, 1983, 1984).



twice had a much more fibrous root system than the seedlings which were not undercut, although total root weight was not significantly different. The undercut treatment (U2) reduced overall seedling grade (Figure 3) but this actually increased survival because of the improved root system.

Table 5. Duncan's multiple range test for undercutting treatments as it affects various seedling trait means

| Undercutting | Root Collar Diameter (inches) | Root Dry Weight (grams) | Shoot Dry Weight (grams) | Root/Shoot Ratio (dry weight) | Seedling Grade (caliper) |
|---|---|---|---|---|---|
| U1 (no undercutting) | .17 a[a/] | .87 a | 2.18 a | 1:2.63 a | 1.70 a |
| U2-(undercut once in July, once in September) | .16 b | .87 a | 1.80 b | 1:2.14 b | 1.94 b |

a/ Means with the same letter are not significantly different at alpha=0.05.

Seedling grades were significantly affected by year (Figure 4). The best year for grade 1+ and 1 seedling production was 1984, but this was also the most variable year. However, greater than 90% of all the seedlings graded were grade 2 or better for all three years.

Survival and Growth

One year survival was significantly affected by the planting year, location, seed bed density and undercutting treatments (Table 6).

Table 6. Probability of greater F-values for the factorial effects for all nine locations combined.

| Source of Variation | 1-Year Winter Survival a/ | 2-Year Height b/ | 2-Year Caliper b/ |
|---|---|---|---|
| Year | 0.0001 | 0.0224 | 0.0001 |
| Location | 0.0001 | 0.0001 | 0.0001 |
| Seed Bed Density | 0.0001 | 0.0001 | 0.0001 |
| Lateral Treatment | 0.1405 | 0.3741 | 0.9430 |
| Undercut Treatment | 0.0001 | 0.0002 | 0.0001 |

a. Based on nine locations
b. Based on five locations

Two year height and caliper growth was significantly affected by planting year, location, seed bed density, and undercut treatment. The year effect on survival and growth is summarized in Table 7. The rainfall patterns in 1982 and 1984 were erratic and extended period of drought occurred in localized areas. Weather conditions were more favorable during 1983 and seedling survival was consistently high over all locations that year.

Figure 3. The effects of undercutting on seedling caliper grade averaged across three years (1982, 1983, 1984).

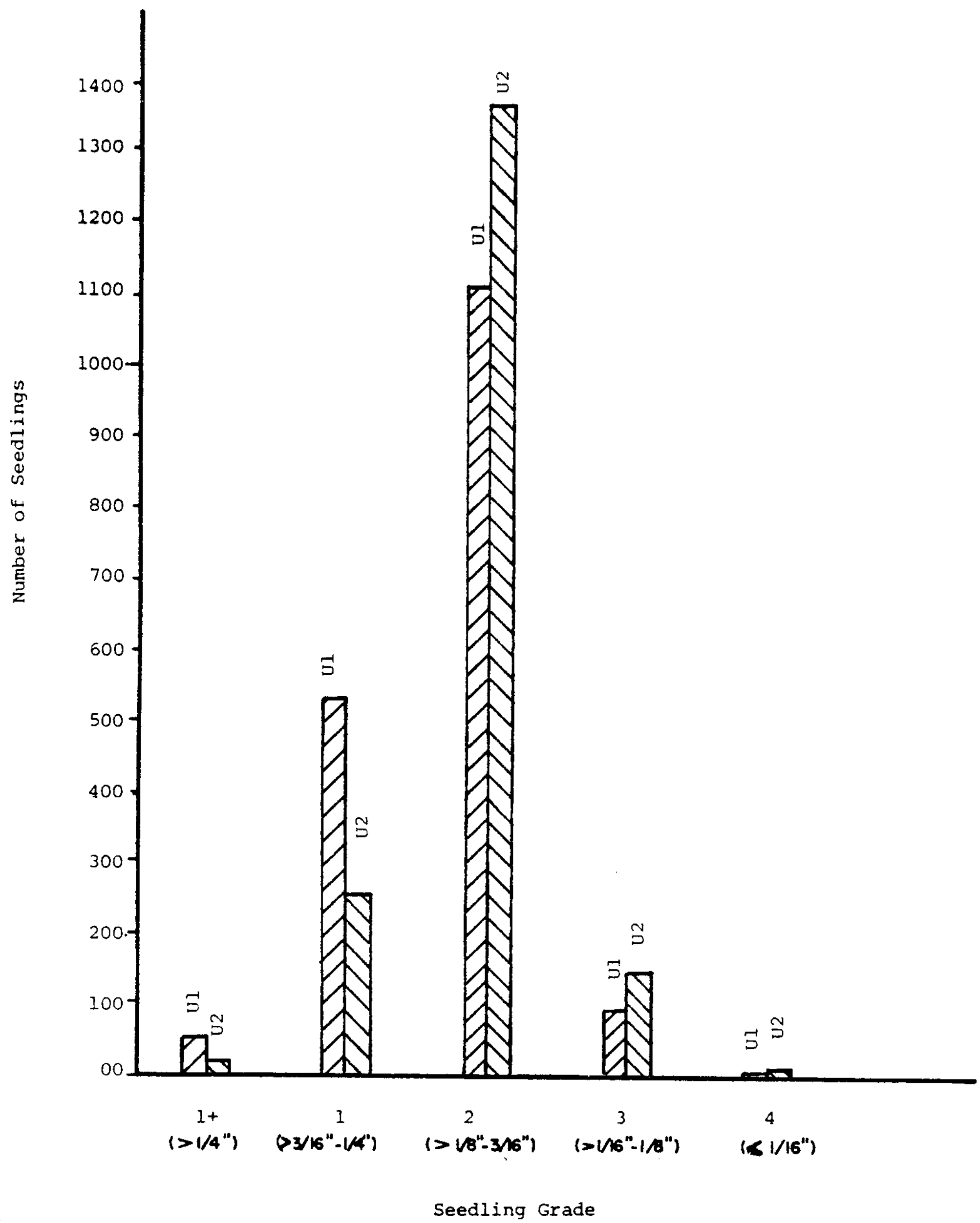


Figure 4. The effect of year of nursery sowing on seedling caliper grade averaged across all treatments.

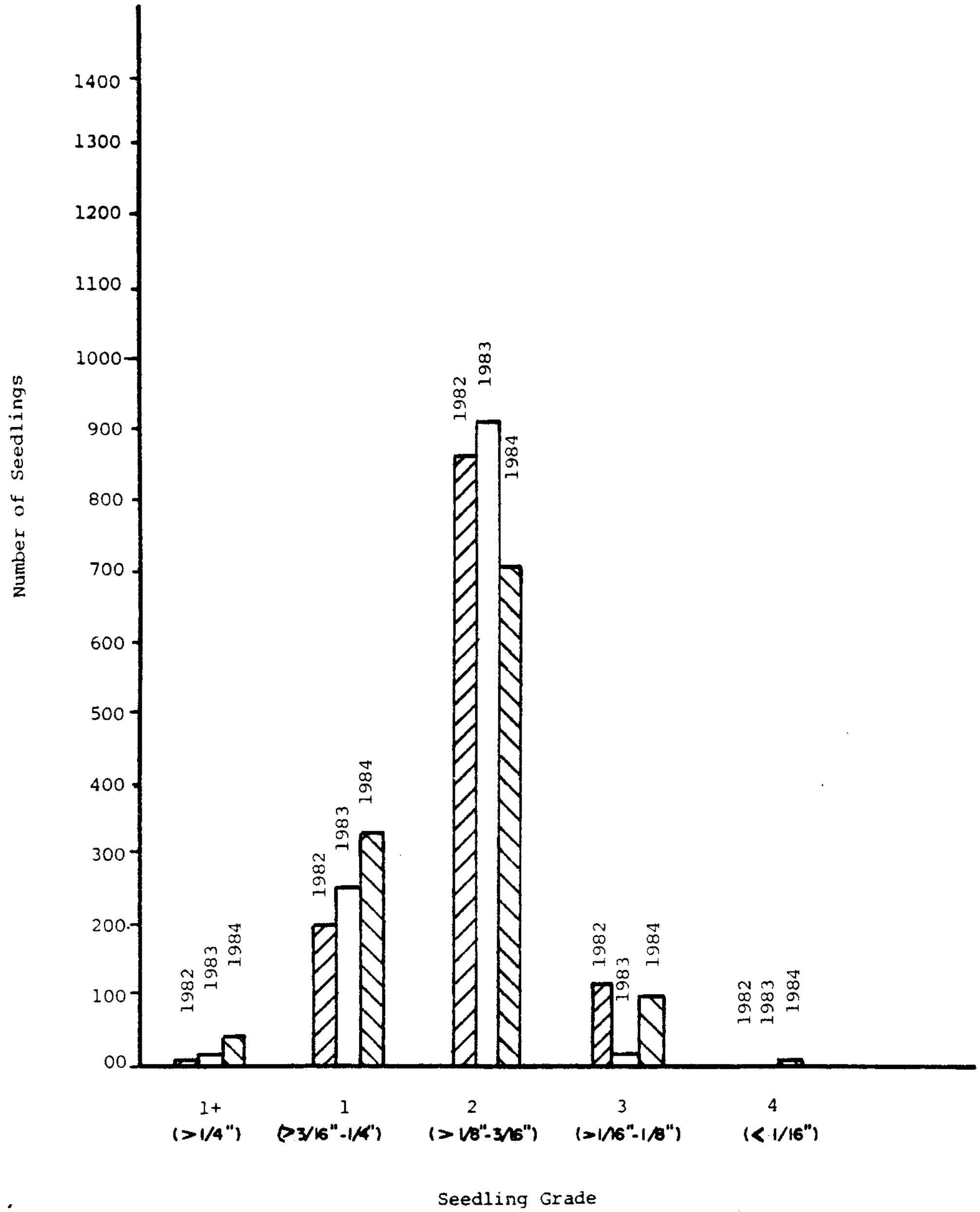


Table 7. Duncan's multiple range test for year effect on survival and growth.

| Year | 1-Year Winter Survival(%) a/ | 2-Year Height(ft.) b/ | 2-Year Caliper(in.) b/ |
|---|---|---|---|
| 1982 | 69.1 b | 3.2 b | 0.89 a |
| 1983 | 97.4 a | 3.4 a | 0.75 b |
| 1984 | 66.7 b | | |

Means with the same letter are not significantly different at alpha level=0.05.

a. Based on nine locations
b. Based on five locations

The planting location was an extremely important factor influencing seedling survival and growth (Table 8). One year survival was extremely good on six locations (survival range 93.5 to 99.2%). These six locations represented four deep sandy sites (2, 3, 5, 8) one western fringe site (4) and the average site (6). The remaining three locations (1, 7, 9) all western fringe sites, had poor survival (13.9%, 37.0% and 69.7%, respectively).

Growth measured by two year height and groundline caliper was best on the "average" site (6) followed by the deep sand location (3). There was no significant difference in height or caliper for the remaining three locations.

Table 8. Duncan's multiple range test for location effect on survival and growth for all locations combined.

| Location | 1-Year Winter Survival(%) | 2-Year Height(ft.) | 2-Year Caliper(in.) |
|---|---|---|---|
| 1 (w.f.) | 13.9 d | failed | failed |
| 2 (sand) | 95.7 a | 2.8 c | 0.78 c |
| 3 (sand) | 97.8 a | 3.6 b | 1.01 b |
| 4 (w.f.) | 97.6 a | 2.5 c | 0.56 c |
| 5 (sand) | 95.4 a | 2.6 c | 0.58 c |
| 6 (avg) | 99.2 a | 5.1 a | 1.14 a |
| 7 (w.f.) | 37.0 c | | |
| 8 (sand) | 93.5 a | | |
| 9 (w.f.) | 69.7 b | | |

Note: Means with the same letter are not significantly different at alpha=0.05.
(w.f.=western fringe; sand=deep sand; avg=average site)

Seed bed density significantly affected one year survival (Table 9). The 24 seedlings per square foot density had significantly better survival than the 32 or 40 densities after the first growing season for all locations combined (79.3 vs 78.4 and 77.4%, respectively). Looking at the three locations with poor survival, the lower density seedlings (24) provided a 6.1% survival increased (60.1 vs 54.0) over the higher density trees (40).

Table 9. Duncan's multiple range test for density effect on survival and growth for all locations combined.

| Density | 1-Year Survival(%) | 1-Yr. Survival Locations 1,7,9 | 2-Year Height(ft.) | 2-Year Caliper(in.) |
|---|---|---|---|---|
| 24 | 79.3 a | 60.1 a | 3.5 a | 0.83 a |
| 32 | 78.4 b | 56.1 b | 3.4 b | 0.82 b |
| 40 | 77.4 c | 54.0 c | 3.3 c | 0.79 c |

Note: Means with the same letter are not significantly different at alpha level=0.05.

Two year height and caliper measurements were significantly influenced by the density levels (Table 9). The tallest and largest caliper seedlings were from the lowest density level (24). The smallest height and caliper measurements were from the highest density (40).

Undercutting in July and September produced a more fibrous root system and significantly increased survival over the no undercut treatment (79.5 vs 77.2%-Table 10). Again, looking at the three locations with poorest survival, the July and September undercut treatment (U2) gave a 4.9% survival increase (59.2 vs 54.3) over the no undercut (U1) treatment. The two undercuts (U2) slightly reduced two year seedling height and caliper but this may not be operationally meaningful since survival was improved by the U2 treatment.

Table 10. Duncan's multiple range test for undercut effect on survival and growth for all locations combined.

| Undercut | 1-Year Survival(%) | 1-Yr Survival Locations 1,7,9 | 2-Year Height(ft.) | 2-Year Caliper(in.) |
|---|---|---|---|---|
| U1 | 77.2 b | 54.3 a | 3.4 a | 0.83 a |
| U2 | 79.5 a | 59.2 b | 3.3 b | 0.80 b |

Note: Means with the same letter are not significantly different at alpha=0.05.
(U1=no undercut, U2=undercut in July and September)

Looking at seed source, the current operationally treated drought hardy seedlings (32L2U1) gave an average 7.2% increase in survival over the "woods run" South of Highway 190 checklot (Table 11). Survival was improved at all nine locations by using the drought hardy seed source, and ranged from a 0.4 to a 22% increase. The "drought hardy" seedlings were significantly better in height (3.4 vs 2.9 ft.) and caliper (0.9 vs 0.7 in.).

Table 11. Duncan's Multiple Range Test for operation drought hardy vs woods run seedlots averaged across all locations.

| Seed Source | 1-Year Survival(%) | 2-Year Height(ft.) | 2-Year Caliper(in.) |
|---|---|---|---|
| "Drought Hardy" | 78.0 a | 3.4 a | 0.9 a |
| "Woods run" checklot | 70.8 b | 2.9 b | 0.7 b |

## CONCLUSIONS

The nursery treatments did produce morphologically different seedlings. Decreasing seed bed density from 40 to 32 to 24 seedlings per square foot increased root collar diameter and gave a better seedling grade. Undercutting reduced root collar diameter and root dry weights, and lowered seedling grade on a caliper basis. However, it produced a much more fibrous root system. Monthly lateral root pruning treatments increased root and shoot dry weights but did not significantly change seedling caliper, root/shoot ratio, or grade.

These morphological differences resulted in improved field survival. The 24 seedlings per square foot density gave better one-year survival than the 32 and 40 seedlings per square foot treatments for all nine locations combined (79.3 vs 78.4 vs 77.4%, respectively). Looking at the three sites with poor survival, decreasing bed density gave a 6.1% increase in survival (60.1 vs 54.0).

The lateral root pruning treatments did not significantly affect survival or growth.

Undercutting twice a year in July and September produced a more fibrous root system that improved survival by 2.3% over the no undercut treatment (79.5 vs 77.2) across all nine locations. Undercutting improved survival by 4.9% (59.2 vs 54.3) on the three sites with poor survival.

Decreasing bed density (from 40 to 24 seedlings per square foot) significantly increased seedling height and caliper at age two (by .2 ft. and .04 in.). The no undercut treatment produced larger seedlings at age two but this treatment reduced survival.

Seed source was very important. The "drought hardy" seed source developed by the Texas Forest Service averaged 7.2% better survival than the "woods run" checklot (78.0 vs 70.8) when averaged across all nine locations. The "drought hardy" seedlings were significantly taller (3.4 vs 2.9 ft.) and larger (0.9 vs 0.7 in.) in groudline caliper than the checklot.

Planting location and year strongly influenced survival and growth. For best survival on potentially droughty sites, geneticall improved "drought hardy" seedlings should be grown near the 24 seedling per square foot density and undercut twice a year (near July and September) to produce a more fibrous root system. Lateral pruning had no effect on survial and can be done as necessary to ensure lifting and planting efficiency.

On sites where survival is not expected to be a problem, seedling density can be increased (up to 40 seedlings per square foot) to lower nursery costs without appreciably affecting survival or growth.

## ACKNOWLEDGEMENTS

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# NURSERY CULTURAL PRACTICES AFFECT FIELD PERFORMANCE OF LONGLEAF PINE

Glyndon E. Hatchell[1]

Abstract.--A nursery and an outplanting study of longleaf pine (*Pinus palustris* Mill.) identify nursery cultural practices for increasing survival and early growth of 1-0 bare-root seedlings planted on deep sandy sites. The best overall field performance has resulted from the following combination of treatments: (1) inoculation of fumigated nursery soil with *Pisolithus tinctorius* (Pt) during spring sowing; (2) low seedbed density (65 to 86 seedlings/$m^2$); (3) vertical pruning of lateral roots during summer and early fall; and (4) medium fertilizer applications spaced throughout the growing season for production of seedlings with root-collar diameters $\geq$ 1.2 cm. Root pruning increases the development of second- and third-order lateral roots, the number of short roots, and the number of ectomycorrhizae on the root system, and it reduces shoot/root ratio. Morphological characteristics of seedlings suitable for planting on deep sandy sites are a root-collar diameter $\geq$ 1.2 cm, a low shoot/root ratio, and a large root system with numerous lateral and short roots and abundant Pt ectomycorrhizae.

Additional keywords: Seedling quality, survival, height growth, diameter growth, *Pinus palustris*, *Pisolithus tinctorius*.

Scientists at the Institute for Mycorrhizal Research and Development are assessing nursery cultural practices for producing bare-root longleaf pine (*Pinus palustris* Mill.) seedlings that survive and grow well on deep sands and other stressful sites. The results of a nursery study and an outplanting study are presented here.

## NURSERY STUDY

### METHODS

The study was established in the Brunswick Pulp and Land Company nursery located near Jesup, Georgia. A split-plot experiment with five replications was installed in nursery beds 1.22 m wide. Three treatment variables — seedbed density, ectomycorrhizal inoculation, and season of sowing — were assigned to main plots, which were 3.05 m lengths of nurserybed. Main plots were divided in half and lateral roots were pruned in one-half and not in the other. Arasan®-coated longleaf pine seeds were sown in eight drills 15 cm apart on October 21, 1981 (fall sowing), and on March 8, 1982 (spring sowing).

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Three ectomycorrhizal treatments were: (1) 0.81 liter/$m^2$ of soil surface of vegetative inoculum of *Pisolithus tinctorius* (Pers.) Coker & Couch (Pt) mixed with the upper 10 cm of soil 1 week after soil fumigation with 440 kg/ha of methyl bromide under clear plastic (Marx et al. 1984); (2) natural inoculation (NI) by air-borne spores of ectomycorrhizal fungi after soil fumigation; and (3) no fumigation of soil (NF) and no inoculum added. Seedbed densities were 86, 129, and 172 seedlings/$m^2$ from fall sowing and thinning on March 24, 1982, and 129 seedlings/$m^2$ from spring sowing and thinning on May 20, 1982. Lateral-root pruning consisted of severing lateral roots to a 20-cm depth during late July and late October 1982.

When nursery beds were prepared in mid-October 1981, all plots received 560 kg/ha of 20-20-20 fertilizer. Analysis of soil samples collected from the 0 to 15 cm depth on October 21, 1981, showed 340 ppm total N, 65 ppm available P, and 24, 220, and 26 ppm of exchangeable K, Ca, and Mg, respectively. Soil pH was 5.1, and organic matter content was 1.6%. All soil analyses were done by A&L Agricultural Laboratories, Inc., Memphis, Tennessee. Seedlings received three top dressings of fertilizer during the 1982 growing season. Materials applied were 168 kg/ha of 10-10-10 in June, 112 kg/ha of 18-46-0 in July, and 37 kg/ha of N in ammonium nitrate in August. Fungicide applications were 11.2 kg a.i./ha of Captan® in October and November 1981; 0.56 kg a.i./ha of benomyl in July 1982; 0.42 kg a.i./ha of triadmefon in July 1982; and 1.12 kg a.i./ha of ferbam in July and September 1982. Herbicide applications were 14 liter/ha of Modown® in October 1981 and June 1982 and 3.5 liter/ha of Poast® in July 1982. Needles were clipped to 10- to 15-cm length in July and September 1982, and roots were undercut at 20-cm soil depth in August 1982.

Twenty-four seedlings per subplot (three seedlings lifted together from random points within each of the eight seed drills) were collected in December 1982. Ectomycorrhizal abundance, root-collar diameter (RCD), fresh shoot and root weights, and shoot/root ratio were determined on these seedlings. Analysis of variance and Duncan's multiple range tests were used to compare means of the 12 main-plot treatments.

## RESULTS AND DISCUSSION

Seedbed density and ectomycorrhizal treatments significantly affected RCD of 1-0 longleaf pine seedlings (table 1), whereas lateral root-pruning did not. Seedlings produced at seedbed densities of 86/$m^2$ had significantly larger RCD than seedlings produced at 129 or 172/$m^2$. Also, seedlings grown in fumigated soil with either Pt or NI treatments were significantly larger in RCD than seedlings grown in NF soil. Spring-sown Pt and NI seedlings grown at a seedbed density of 129/$m^2$ had significantly larger RCD than fall-sown NF seedlings grown at the same density. The largest number of seedlings with RCD 1.2 cm and larger was produced at the 86/$m^2$ seedbed density. Seedlings with RCD 1.2 cm and larger are preferred by some forest managers because smaller seedlings cannot withstand several weeks of cold storage and usually have poor survival and growth after planting (White 1981, South and Mexal 1984). *Rhizoctonia* blight (*Rhizoctonia solani* Kuehn) reduced the number of plantable seedlings, but this serious disease can be controlled with timely applications of fungicides (Barnard 1979).

Table 1.--Mean root-collar diameter (RCD) and number of plantable 1-0 long-leaf pine seedlings based on minimum RCD, by nursery cultural treatments[1]

| Sowing season, seedbed density, and ectomycorrhizal treatment[2] | Root-collar diameter | Plantable seedlings by minimum RCD (cm) 0.9 | 1.2 |
|---|---|---|---|
| | cm | Number/m² | |
| Fall, 86/m² | | | |
| Pt | 1.24a | 85d | 55a |
| NI | 1.23a | 85d | 51ab |
| NF | 1.09bc | 76d | 29d |
| Fall, 129/m² | | | |
| Pt | 1.12b | 110bc | 47abc |
| NI | 1.10bc | 116ab | 40bcd |
| NF | 1.02de | 99c | 13d |
| Spring, 129/m² | | | |
| Pt | 1.08bc | 104bc | 32d |
| NI | 1.10bc | 105bc | 36cd |
| NF | 1.01de | 71d | 11e |
| Fall, 172/m² | | | |
| Pt | 1.08bc | 124a | 33d |
| NI | 1.06cd | 128a | 33d |
| NF | 1.00e | 74d | 6e |

1 Within columns treatment means followed by a common letter are not significantly different at *P* = 0.05.

2 Pt = *Pisolithus tinctorius*; NI = natural inoculation with air-borne spores after soil fumigation; NF = nonfumigated soil with natural inoculation.

Pt or NI seedlings grown at the 86/m² seedbed density had significantly heavier shoots and roots than seedlings grown at higher density or in NF soil (table 2). Soil fumigation a week before either fall or spring sowing effectively controlled pythiaceous fungi and plant parasitic nematodes, whereas, roots of NF seedlings exhibited severe feeder-root necrosis. The lowest shoot/root ratios were for spring-sown Pt or NI seedlings grown at the 129/m² seedbed density. Highest shoot/root ratios were for fall-sown Pt or NI seedlings grown at the 172/m² seedbed density and for fall-sown NF seedlings grown at all three seedbed densities. Lateral-root pruning significantly decreased shoot/root ratios and significantly increased fresh weight of seedling roots.

Table 2.--Fresh weight of shoots and roots and shoot/root ratio of 1-0 longleaf pine seedlings, by nursery cultural treatments[1]

| Sowing season, seedbed density, and ectomycorrhizal treatment[2] | Fresh weight | | Shoot/root ratio |
|---|---|---|---|
| | Shoots | Roots | |
| | - - - - grams - - - - | | |
| Fall, 86/m² | | | |
| Pt | 39.1a | 12.6a | 3.14cd |
| NI | 36.3b | 12.0a | 3.06de |
| NF | 24.8de | 7.5c | 3.35abcd |
| Fall, 129/m² | | | |
| Pt | 28.8c | 9.0b | 3.25bcd |
| NI | 27.1cd | 8.6b | 3.19bcd |
| NF | 19.7g | 5.5d | 3.61a |
| Spring, 129/m² | | | |
| Pt | 20.2g | 7.3c | 3.78f |
| NI | 21.6g | 7.7c | 2.85ef |
| NF | 14.8h | 4.6de | 3.18bcd |
| Fall, 172/m² | | | |
| Pt | 23.3ef | 6.8c | 3.43abc |
| NI | 23.1ef | 6.9c | 3.36abc |
| NF | 14.7h | 4.3e | 3.48ab |

[1] Within columns treatment means followed by a common letter are not significantly different at $P = 0.05$.

[2] Pt = *Pisolithus tinctorius*; NI = natural inoculation with air-borne spores after soil fumigation; NF = nonfumigated soil with natural inoculation.

Lateral-root pruning also significantly increased abundance of ectomycorrhizae of all fungal species, and spring-sown Pt seedlings had significantly greater total ectomycorrhizae than seedlings from any other main-plot treatment. On spring-sown Pt seedlings grown at the 129/m² seedbed density, 33% of feeder roots were ectomycorrhizal compared to 24% on spring-sown NI or NF seedlings. On fall-sown NI seedlings grown at the 86/m² seedbed density, only 16% of roots were ectomycorrhizal. The Pt index is the proportion of feeder roots with Pt ectomycorrhizae in relation to total ectomycorrhizae formed by all fungi. The Pt index was significantly higher on spring-sown Pt seedlings than on fall-sown Pt seedlings. The effectiveness of the Pt treatment in fall sowing was decreased by natural competition from air-borne spores of other fungi as evidenced by abundant fruiting bodies throughout the nursery.

Lateral-root pruning significantly increased root weight and total ectomycorrhizae and significantly reduced shoot/root ratio. These changes may increase survival of longleaf pine planted on droughty sandy sites. Lateral-root pruning obviously increased the number of second- and third-order lateral roots, resulting in an increase in feeder roots and ectomycorrhizae, but it had no apparent effect on the number of first-order lateral roots. Venator (1983) reported that lateral-root pruning of longleaf pine seedlings failed to stimulate new first-order lateral roots. Brown (1964) observed that a high percentage of longleaf pine seedlings produced at seedbed densities $<172/m^2$ are "carrot-rooted". He also found that lateral-root pruning during the growing season induced more abundant fibrous roots on the severed roots, enabling seedlings to withstand the lifting operation better than unpruned seedlings with deeply penetrating fibrous roots.

## OUTPLANTING STUDY

### Seedling Production

Longleaf pine seedlings for the outplanting study were produced at the Whitehall Experimental Nursery, Athens, Georgia, during the 1982 growing season. Nursery beds containing a uniform mixture of forest topsoil, sand, and milled pine bark (2:1:1 v/v) were fumigated with methyl bromide under clear plastic. Treatment combinations consisted of two ectomycorrhizal conditions (Pt or NI) x four seedbed densities (65, 97, 129, or 161 seedlings/$m^2$) x two lateral-root pruning treatments (pruned or unpruned). Pt vegetative inoculum was applied at 1.08 liter/$m^2$ of soil surface and mixed with the upper 10 cm of surface soil. Lateral-root pruning was done by cutting through the soil midway between seed drills to 20-cm depth on August 16 and October 8. Seedlings were not undercut, and tops were not clipped.

Analysis of soil samples collected at 0- to 15-cm depth on March 29 showed 400 ppm total N, 30 ppm available P, and 36, 190, and 12 ppm of exchangeable K, Ca, and Mg, respectively. Soil pH was 4.8; and organic matter content was 1.3%. Then longleaf pine seeds were sown at 15-cm spacing. Plots were thinned to assigned seedbed densities on May 25. All plots received the same fertilizers and pesticides. Top dressings of ammonium nitrate with 56 kg/ha of N and muriate of potash with 28 kg/ha of K were applied on June 8, June 29, July 28, August 16, and September 15. Muriate of potash was applied in side dressings to avoid K deficiency in the sandy soil mixture (Brendemuehl and Mizell 1978).

Seedlings were lifted on January 3, 1983, and the number of plantable seedlings with RCD $\geq$ 1.0 cm was determined. Seedbed densities of 65, 97, 129, and 161 seedling/$m^2$ produced 57, 66, 75, and 76 plantable seedlings/$m^2$, respectively. Five bundles of 25 plantable seedlings per treatment were packed in shipping bags and stored at 5 °C for 2 days before planting. Mean RCD's of planting stock were 1.44, 1.32, 1.27, and 1.23 cm, for seedbed densities of 65, 97, 129, and 161 seedlings/$m^2$, respectively. At seedbed densities $\leq$ 129 seedling/$m^2$, mean RCD of Pt seedlings was 0.05 to 0.08 cm larger than NI seedlings (table 3). Ectomycorrhizal evaluation of Pt treatments showed that only seedlings grown at seedbed densities of 65, 97, and 129 seedlings/$m^2$ coupled with lateral-root pruning had Pt indices >50, the critical value required for measurable treatment response on reforestation sites.

Table 3.--Root-collar diameters of longleaf pine seedlings before planting on a sandy site in the South Carolina sandhills, by seedbed density, lateral-root pruning treatment, and ectomycorrhizal treatment[1]

| Seedbed density (seedlings/m$^2$) | Root pruned | | Unpruned | | Means | | |
|---|---|---|---|---|---|---|---|
| | Pt | NI | Pt | NI | Pt | NI | Density |
| | - - - - - - Root-collar diameter (cm) - - - - - - | | | | | | |
| 65 | 1.51 | 1.40 | 1.46 | 1.40 | 1.48 | 1.40 | 1.44 |
| 97 | 1.31 | 1.28 | 1.39 | 1.31 | 1.35 | 1.30 | 1.32 |
| 129 | 1.27 | 1.24 | 1.32 | 1.25 | 1.30 | 1.25 | 1.27 |
| 161 | 1.25 | 1.26 | 1.22 | 1.21 | 1.24 | 1.23 | 1.23 |
| Overall ectomycorrhizal means - - - - - - - - - - - - - - - - | | | | | 1.34 | 1.29 | |

[1] Pt = *Pisolithus tinctorius*; NI = natural inoculation with air-borne spores after soil fumigation.

## Experimental Design for Outplanting Study

Seedlings were outplanted near Aiken, South Carolina, on a sandhills site with sand extending 1- to 2-m deep. The area had been clearcut, sheared, root raked, and disked.

Experimental design was a split plot with randomized blocks and five replications. Pt and NI treatments were assigned to main plots, and subplots were assigned to combinations of the four seedbed densities and the two lateral-root pruning treatments. Twenty-five seedlings per subplot were planted 0.9 m apart in rows 2.4 m apart. Between main plots were 6.1 m isolation strips which were not planted.

## RESULTS

All three factors, seedbed density, lateral-root pruning, and ectomycorrhizae, significantly affected second-year longleaf pine survival on the deep sandy site. Overall means for survival were 74, 73, 77, and 66% for seedbed densities of 65, 97, 129, and 161 seedlings/m$^2$, respectively. Survival averaged 84% for lateral-root pruning vs. 61% for unpruned seedlings. It was 79% for Pt vs. 66% for NI seedlings. Table 4 shows treatment means and significant differences among subplots within Pt or NI main plots. The effects of lateral-root pruning on seedling survival were quite strong. Over the four levels of seedbed density, Pt seedlings had survival ranging from 84 to 91% for the pruned treatment and 65 to 81% for the unpruned treatment, and NI seedlings had survival from 74 to 86% for pruned vs. 42 to 61% for unpruned treatment.

Table 4.--Effects of nursery cultural practices on survival and growth of longleaf pine seedlings on a deep sandy soil in the South Carolina sandhills 2 years after planting[1]

| Ectomycorrhizae, lateral-root pruning treatment, and seedbed density[2] | Survival | Height | Root-collar diameter | Seedling volume index [3] | Plot volume index [4] |
|---|---|---|---|---|---|
| | % | cm | cm | $cm^3$ | $cm^3$ |
| Pt ectomycorrhizae | | | | | |
| Pruned laterals | | | | | |
| $65/m^2$ | 91a | 14.8a | 2.81a | 132a | 3,060a |
| $97/m^2$ | 90a | 11.4bc | 2.65ab | 88bc | 1,960b |
| $129/m^2$ | 91a | 10.0c | 2.66ab | 76bcd | 1,720bc |
| $161/m^2$ | 84a | 9.6c | 2.56bc | 68cd | 1,400cde |
| Unpruned laterals | | | | | |
| $65/m^2$ | 66b | 12.2b | 2.65ab | 97b | 1,600bcd |
| $97/m^2$ | 63b | 9.2c | 2.53bc | 65cd | 1,020e |
| $129/m^2$ | 81a | 10.2bc | 2.47bc | 76bcd | 1,530bcde |
| $161/m^2$ | 65b | 9.3c | 2.38c | 62d | 1,010e |
| Mean Pt[5] | 79** | 10.8(NS) | 2.59(NS) | 83(NS) | 1,660(NS) |
| NI ectomycorrhizae | | | | | |
| Pruned laterals | | | | | |
| $65/m^2$ | 86a | 14.1a | 2.85a | 128a | 2,760a |
| $97/m^2$ | 78a | 10.2b | 2.72ab | 84b | 1,640b |
| $129/m^2$ | 79a | 8.3b | 2.47cd | 57c | 1,150bc |
| $161/m^2$ | 74a | 9.6b | 2.45cd | 66bc | 1,200bc |
| Unpruned laterals | | | | | |
| $65/m^2$ | 51bc | 10.5b | 2.58bc | 80bc | 1,050cd |
| $97/m^2$ | 61b | 9.9b | 2.55bc | 69bc | 1,050cd |
| $129/m^2$ | 57b | 8.6b | 2.41cd | 55c | 770cd |
| $161/m^2$ | 42c | 8.5b | 2.34d | 56c | 570d |
| Mean NI | 66 | 10.0 | 2.54 | 74 | 1,270 |

1 Treatment means within columns and ectomycorrhizal treatments followed by a common letter are not significantly different at $P = 0.05$.
2 Pt = *Pisolithus tinctorius*; NI = natural inoculation with air-borne spores after soil fumigation.
3 Seedling volume index = (root-collar diameter)$^2$ x height.
4 Plot volume index = sum of seedling volume index per plot.
5 ** indicates that means for Pt are significantly different from NI at $P = 0.01$. NS indicates means are not significantly different at $P = 0.05$.

Seedbed density and lateral-root pruning significantly affected seedling growth after 2 years, but ectomycorrhizae did not. Significant seedbed density x lateral-root pruning interactions were observed in terms of height ($\underline{P}$ = 0.05), seedling volume index ($\underline{P}$ = 0.05), and plot volume index ($\underline{P}$ = 0.01). Growth responses to lateral-root pruning were greater at low than at high seedbed densities. Seedling volume index and plot volume index are surrogate measures of seedling biomass and plot biomass (Hatchell et al. 1985). Seedlings grown at the 65/$m^2$ seedbed density with lateral-root pruning had the largest RCD's at lifting and grew the best after outplanting (table 4). These growth responses are preliminary, because only 37% of seedlings on all plots were in active height growth (seedlings having heights $\geq$ 10 cm and RCD $\geq$ 2.5 cm).

## CONCLUSIONS

A nursery study and an outplanting study showed that lateral-root pruning coupled with the lowest levels of nurserybed density, respectively 86 and 65 seedlings/$m^2$, produced the highest quality longleaf pine 1-0 seedlings, based on their morphological characteristics and survival and growth through 2 years on a deep sandy site. Pt inoculation of fumigated soil before spring sowing significantly increased survival but not growth compared to natural inoculation.

Row seeding at uniformly low seedbed density and lateral-root pruning should replace the conventional broadcasting seeding at high seedbed densities (about 130 seedlings/$m^2$). Spring sowing in fumigated soil inoculated with Pt will improve seedling quality, but careful nursery management will be required for maximum effectiveness of this treatment. Production of large (RCD $\geq$ 1.2 cm), high-quality longleaf pine seedlings requires effective disease control, optimum soil fertility, low seedbed density, and lateral-root pruning.

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