Tree Improvement and Nursery Technology

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EFFECTS OF TOP-PRUNING ON SURVIVAL OF SOUTHERN PINES AND HARDWOODS

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Abstract—Two schools of thought exist regarding top-pruning bareroot seedlings. One school favors top-pruning due to the economic advantages. Top-pruning can reduce the production of cull seedlings (increase crop value) as well as increase the chance of survival after outplanting. Published studies suggest that top-pruning can increase overall survival of loblolly pine and longleaf pine by 7 and 13 percentage points, respectively. Pruning various hardwood species (mainly after lifting) increased average survival by 5 percentage points. The benefits of top-pruning appear greater when seedlings experience stress after planting and when non-pruned seedlings have low root-weight ratios (root dry weight/total seedling dry weight). On some droughty sites, a seedling with a 0.3 root-weight ratio might have a 26 percentage point higher chance of survival than a seedling with a 0.2 root weight ratio. In most studies with hardwoods or multinodal pine species, height growth is stimulated so that after 3 years in the field, pruned seedlings have caught up to the heights of non-pruned seedlings.

One school advises against top-pruning in the nursery. Some believe the concern for a balance between roots and shoots at planting has been greatly overemphasized. Others believe that top-pruning is not natural and that cutting the shoot will anthropomorphically hurt the seedling. A few believe top-pruning will result in forked trees at harvest (with the fork just above ground level). Those who advise against top-pruning tall seedlings usually do not give justifications that are based on economics or field performance.

INTRODUCTION

Nursery managers have been improving the "transplantability" of bare-root seedlings by top-pruning for over 300 years. John Evelyn (1679) gave a prescription for cutting oak (*Quercus sp.)* seedlings in the nursery to a height of 3 centimeters (cm). After resprouting, some growers applied a second pruning at a 15-cm height. Two hundred years later, Fuller (1884) reported that "All kinds of forest trees may be, and nearly all should be pruned at time of transplanting." Brisbin (1888) observed that many planting failures could be explained by not pruning enough. Fernow (1910) stated that "...pruning is to be done at the time of planting, when it is needful to restore the balance between the branch system and the root system, the latter often having been curtailed in the operation of transplanting the tree." Toumey (1916) stated that the more severely the root system is injured in lifting the trees, the greater the necessity for pruning the tops. Today, more than 90 percent of nursery managers in the Southern United States and Australia top-prune seedlings (Duryea 1986, Duryea and Boomsma 1992). Most managers apply this practice to improve the root-weight ratio[2] of both bare-root seedlings and rooted cuttings.

Even though it has been practiced for centuries, two schools of thought have evolved regarding top-pruning. Some believe that top-pruning is not beneficial and should never be practiced. Others believe top-pruning increases the chances of survival and increases crop value. This review paper summarizes top-pruning studies mainly from southern forest nurseries and was written in hopes of clarifying some of the differences in philosophy between the two schools.

METHODS

Published studies were compiled for loblolly pine (*Pinus taeda* L.), longleaf pine (*Pinus palustris* Mill.), slash pine *(Pinus elliottii* Englm.), eastern white pine (*Pinus strobus* L.) and various hardwood species. Eight unpublished studies on loblolly pine were also included. Survival data from these studies were used to develop three regression equations relating survival of pruned seedlings (Y) to survival of non-pruned seedlings (X).

RESULTS AND DISCUSSION

Effect on Survival

Survival of loblolly pine was increased by top-pruning (table 1). In tests where survival of non-pruned seedlings was high, there was little or no increase in the survival rate.

Table 1—Overall effect of top-pruning on seedling survival of loblolly pine, longleaf pine, and hardwood species

		Survival rate	
Species	Number of tests	Pruned	Non-pruned
		- - - - - *Percent*	- - - - -
Loblolly pine	28	86	79
Longleaf pine	20	59	48
Hardwoods	17	90	85

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[2] Root-weight ratio (RWR) is determined by dividing the dry weight of the root system by the dry weight of the total seedling. The term is inherently easier to comprehend than the root-shoot ratio. The RWR is also less confusing, since many practitioners believe the root-shoot ratio compares shoot height with taproot length.

However, as environmental stresses at the planting site increased, top-pruning increased the probability of survival ($Y = 16.9 X^{0.375}$; $R^2 = 0.80$). On one piedmont site in Virginia, top-pruning increased seedling survival by 43 percentage points (Dierauf 1976). For this species an increase in survival may result, in part, from an increase in freeze tolerance (South and others 1993). For the 13 tests where survival of non-pruned seedlings was less than 80 percent, top-pruning increased survival by 16 percentage points.

For longleaf pine, pruning increased overall survival of seedlings by 11 percentage points (table 1). For the 16 comparisons showing a benefit to clipping needles, survival increased by 14 percentage points ($Y = 5.2 X^{0.64}$; $R^2 = 0.90$). Wakeley (1954) warned against "close" pruning of longleaf needles and this might have accounted for the negative results reported by Derr (1963) who pruned needles back to 13 cm.

Top-pruning of eastern white pine had no effect on seedling survival (Dierauf 1997). Data from two studies with slash pine show no statistically significant effect of top-pruning on survival after outplanting (Barnett 1984, Duryea 1990).

Effects of top-pruning on hardwoods were previously reported (South 1996). Due to short heights (< 0.5 meter) and a high survival rate (>79 percent) of most non-pruned seedlings, top-pruning increased average survival by only 5 percentage points (table 1). Therefore, for hardwood seedlings less than 0.5 meters tall, there was no relationship between survival of pruned and non-pruned seedlings ($Y = 75.8 + 0.16X$; $R^2 = 0.05$). However, out of a total of 18 comparisons, only in three studies was the survival rate lower for top-pruned seedlings. There was a 17 percentage point increase in survival for six studies exhibiting a benefit from top-pruning (ranging from +3 to +42 percent).

Importance of Restoring the Balance Between Roots and Shoots

The increase in survival due to top-pruning results from planting seedlings with a higher root-weight ratio (RWR) (i.e., a better "balanced" seedling). A proper balance between roots and shoots is important for good survival of loblolly pine (Larsen and others 1986). At lifting in December, a RWR within the range of 0.27 to 0.35 is preferred to a ratio of less than 0.25 [initial survival = 157.6 + 64.7 ln (RWR); $R^2 = 0.54$]. On some droughty sites, an increase in RWR from 0.2 to 0.3 could increase seedling survival by 26 percentage points. The main reason nursery managers top-prune bare-root seedlings is to improve the RWR.

Improper and Proper Top-pruning

Pruning is a general term that refers to any removal of the foliage, branches, terminal bud, or stem of seedlings. This often vague term includes both "proper" and "improper" pruning. Proper top-pruning meets the objectives of the nursery manager (which might include reducing seedling height at planting, increasing the RWR at planting, increasing seedling uniformity, increasing seed efficiency). Likewise, improper top-pruning fails to meet management objectives. As an example, in some cases a single top-pruning will fail to meet the objective of reducing heights of pines in the nursery (Mexal and Fisher 1984, Haack 1988, Blake and South 1991). When compared to non-pruned seedlings, taller, improperly top-pruned seedlings might exhibit lower outplanting survival (Blake and South 1991). However, proper top-pruning of southern pine seedlings (involving a series of clippings) can reduce seedling height at lifting and this can result in a dramatic increase in field survival (Dierauf 1976, South and Blake 1994). It is now accepted that single top-pruning of loblolly pine or slash pine in the month of August is "improper" since it will likely have no effect on increasing RWR in December. Multiple top-pruning (typically involving three or more clippings) as described by Dierauf (1997) is much more likely to meet management objectives. The first clipping is typically conducted about August 1 and cuts about 10 to 20 percent of the seedlings. The second clipping cuts about 50 percent of the seedlings and is conducted in the last week of August. The third clipping occurs in mid-September about 3 or 4 weeks later (cutting perhaps 33 percent of the seedlings). In years with unusually rapid growth after the equinox, a fourth clipping may be required.

The difference between "proper" and "improper" pruning of pine seedlings depends on the degree of pruning. In some situations, moderate top-pruning (reducing shoot height by 17 percent) can improve survival of loblolly pine by 20 percentage points. However, removal of one needle will have no effect on reducing seedling height and would not result in increased survival. Top-pruning only the terminal bud will have no effect on the root growth potential of loblolly pine (Williams and others 1988). On the other hand, removing the entire shoot (increasing the RWR to 100 percent) will likely kill a loblolly pine seedling. Even removing all but 10 cm of stem (above the root-collar) can greatly increase mortality. Removal of all foliage by hand (leaving an intact stem) will reduce survival of longleaf pine and slash pine (Wakeley 1954). Removing too much foliage will decrease survival since new root growth of pines depends on needle biomass. Therefore, conifer seedlings should not be top-pruned to such an extent as to reduce new root growth or to check shoot growth (Brisbin 1888). However, several hardwoods are quite tolerant of severe top-pruning, and planting of "stumps" is an accepted practice in many tropical countries. This agrees with Toumey (1916) who stated that "On the whole, broadleaved species withstand pruning better than conifers."

Reasons to Top-Prune

Reasons for and against top-pruning are listed in table 2. Individuals in favor of top-pruning usually are so for economic reasons. The primary economic justification for top-pruning in the nursery is to increase field survival. For example, a 10 percent increase in survival might be worth $40 to $50 per hectare (ha). Assuming seedlings in a hectare of nursery can be used to plant 1,000 ha of woodlands, increasing seedling survival by 10 percent on all planting sites would increase crop value by $40,000 to $50,000 per ha. Even when top-pruning increased survival

Table 2—Reasons for and against top-pruning of bare-root seedlings

Stated reasons for top-pruning

- It increases the chance of survival.
- It increases the root/weight ratio.
- It increases crop value by increasing seed efficiency.
- It increases seedling uniformity.
- For some species, it increases freeze tolerance.
- For some species, it increases initial growth after outplanting.
- For some top-blights, it reduces the disease symptoms at lifting.
- For some species, it reduces shipping costs.
- For longleaf pine, it permits lateral root pruning.
- For some hardwoods, it reduces injury to workers during lifting.
- Top-pruning allows managers to fertilize and irrigate to produce large root systems.

Stated reasons against top-pruning

- It is not natural.
- The balance between root and shoot is not important for survival.
- It causes a wound.
- It increases seedling uniformity.
- It alters seedling biochemistry.
- It causes forked seedlings.
- It makes culling of small seedlings difficult.
- It might increase disease.
- For some species, it reduces the probability of having a terminal bud at lifting.
- Top-pruning is not needed when short seedlings with small diameters are produced by withholding fertilization and irrigation.

by 10 percent on only 5 percent of the sites, crop value would increase by $2,000 to $2,500 per ha. Either case would easily justify the cost of top-pruning (about $40 per ha per clipping).

Another economic justification for top-pruning involves increasing seed efficiency. Seed efficiency is defined as the number of plantable seedlings produced per pure live seed. When increasing seed efficiency, top-pruning has a dual benefit. First, multiple top-pruning reduces the number of tall seedlings that exceed the culling limit. In one case where seedlings were top-pruned only once, 77 percent of the crop exceeded a cull limit of 33 cm (Haack 1988). Reducing the number of tall seedlings can be a major economic benefit when tall seedlings end up on the culling room floor. Second, top-pruning tends to reduce the growth of the dominants in the seedbed and allows some of the smaller seedlings to grow into a plantable grade. For pines, this “release” effect occurs mainly when multiple top-pruning is practiced. For example, with one pruning the smaller diameter seedlings might be decreased by 2 percentage points (Mexal and Fisher 1984) but with two prunings, a decrease of 5 percentage points might result (Duryea 1990). Assuming 1.5 million seedlings could be produced without top-pruning, an additional 30,000 to 75,000 plantable seedlings would increase crop value by $1,000 to $2,500 per ha.

Improving outplanting survival will allow some organizations to lower target outplanting densities. Planting fewer trees will not only reduce regeneration costs but will also allow the best genotypes to be planted over more hectares. Nursery managers may also benefit from reduced lifting, culling, and shipping costs. Although safety is sometimes mentioned as a reason to top-prune hardwoods (due to a reduction in eye injuries during hand lifting), this is typically not a driving factor. However, seedling uniformity can be important. In some cases, a nursery with uniform nursery beds will attract and retain more customers. In years with a regional seedling surplus, this will convert to a distinct economic advantage.

An improvement in seedling growth after outplanting is often observed for top-pruned seedlings. Typically the increase in growth allows pruned seedlings to catch up to the heights of non-pruned seedlings at the end of two or three growing seasons (Zaczek and others 1997). For some oaks, the probability of achieving dominance in the canopy is increased by top-pruning (Johnson 1984). For some species, the top-pruning increases the rate of bud flushing and stimulates “free growth” (Colombo 1986). In a few cases, top-pruned seedlings after two growing seasons were taller than non-pruned seedlings (Smith and Johnson 1981, McCreary and Tecklin 1994). However, in one study with white pine, seedlings top-pruned twice were still 15 cm shorter than controls after three growing seasons (Dierauf and others 1995).

Reasons Not to Top-Prune

Students of the “no top-pruning” school can provide several reasons why nursery managers should not top-prune seedlings (table 2). Most of these reasons are not based on economics but are based on feelings instead. One reason given for not top-pruning is that it is not “natural.” However, this is not entirely true since deer, moose, cattle, and rabbits often top-prune both pine and hardwood seedlings. The terminals of many pines are killed in nature by insects. In some areas, 50 percent of the terminal buds of conifers die after outplanting (Colombo 1986). Some believe a live terminal bud is important at time of planting. However, terminal bud abortion is a natural and common occurrence for many angiosperms.

A few believe top-pruning is bad in that it produces a uniform seedling crop. A uniform seedling crop makes it more difficult to cull the bottom 25 percent of the population. With pines and some hardwood species, top-pruning does increase the number of seedlings with forks (Dierauf 1997) and some customers do not like forked trees. However, forks at time of planting affect appearance rather than long-term growth or survival.

Some who advise against top-pruning claim the concern for a balance between roots and shoots has been greatly overemphasized. For example, Kormanik and others (1995) say that a RWR of 0.12 is typical in November and has not affected survival of loblolly pine. Some point to studies in Canada that show no relationship between survival and seedling balance (Racey and others 1983, Bernier and others 1995). A lack of a relationship can be expected when researchers obtain high outplanting survival. Researchers typically achieve higher survival rates than operational planting crews. However, a significant relationship is more likely when some seedlings die due to unfavorable environmental conditions.

Some fear that top-pruning will increase disease. Toumey (1916) was concerned about the introduction of disease since "every cut produces a wound through which spores of fungi may gain access..." As a result, he said, "as little pruning should be done as is necessary to maintain a proper balance between root and shoot." The concern about top-pruning increasing seedling diseases persists today. If some unidentified disease is observed late in the growing season, top-pruning is sometimes suspected of having increased susceptibility to the pathogen.

One year at the Ashe Nursery in Mississippi, brown spot needle blight (*Mycosphaerella dearnessii*) was observed after pruning longleaf pine (Kais 1978). Top-pruning in July and November spread infected needles over the nursery. Even so, periodic clipping of needles during the growing season is recommended as a means to reduce the incidence of brown spot in the nursery. Pruning avoids forming a dense mat of needles and allows a uniform application of fungicides. Some managers who grow longleaf pine apply fungicides both before and after clipping. For drill-sown longleaf, clipping allows managers to do a better job of lateral root pruning which increases survival.

Top-pruning will not increase fusiform rust (*Cronartium quercuum f. sp. fusiforme*) in the nursery since spore flight occurs several months before the first clipping in August. However, Stanley (1986) reported an increase in rust on 3-year-old trees that had been severely top-pruned in the nursery. It seems likely that top-pruning to a height of 10 to 15 cm in the nursery stimulated height growth (and succulent foliage mass) the year after planting. The increase in rust galls at age 3 likely resulted from infection during the year after outplanting (above the 15 cm height). Other management practices that increase seedling growth also increase fusiform rust; these include fertilization, soil cultivation, and use of herbicides for weed control.

Some are concerned that top-pruning in the nursery will affect wood quality when the tree is harvested after 30 years. A similar concern was expressed by Toumey (1928) who stated that "Poor bole form, particularly crookedness, is very commonly caused by damage to the leading shoot or to the terminal bud." He adds that "The loss of the terminal bud very frequently causes double top in pine, spruce, balsam fir and larch." He said the double top causes great loss in the quality of the timber. These statements could lead some to conclude that injury to the terminal bud in the nursery always results in a permanently crooked or forked tree. However, there are no published data to support this belief. Long-term top-pruning studies with oak (*Quercus sp.*) and yellow poplar (*Liriodendron tulipifera* L.) report no problems with tree form. For Monterey pine (*Pinus radiata* D. Don), a fork low to the ground does not affect average tracheid length, spiral-grain angle, average density, or late-wood ratio (Nicholls and Brown 1974). In fact, total volume can be slightly greater for a forked tree. A fork caused by pruning seedlings to a 25 cm height would not be higher than 25 cm from the ground (few pines exhibit permanent forks this close to the ground). Likewise, a fork 1 meter above the ground would not be caused by top-pruning a hardwood back to a 50 cm height in the nursery. Although top-pruning will cause some seedlings to be forked in the year after planting, this fork is ephemeral and certainly does not move up the stem as the tree ages. After the seedlings are outplanted and reach a height of 2 meters, most people cannot tell the difference between a top-pruned and non-pruned loblolly pine. Although a harvested tree with two stems originating 25 cm above ground will produce different amounts and quality of lumber, there are no data to show that top-pruning increases the frequency of these (low forked) trees in a plantation.

Scientific Method

At this point I will digress and touch briefly on the scientific method. The scientific process follows a pattern: define the problem; make observations and collect data; analyze data and form a generalization; formulate a null hypothesis; design a study to test the null hypothesis; draw conclusions; accurately report and publish results; reevaluate generalization. The null hypothesis is rejected only when data from a well-designed study can be used to reject the hypothesis. In the case of lumber quality, the null hypothesis can be stated as: top-pruning in the nursery has no effect on lumber quality. I know of no data from a top-pruning study that can be used to reject this hypothesis. Since researchers cannot prove a null hypothesis, it remains the responsibility of those who reject the null hypothesis (e.g., claim that top-pruning does affect wood quality) to publish data to support their claims. In other words, it is unscientific to reject a null hypothesis using only intuition and assumptions (no matter how often the intuition is accepted by the public).

CONCLUSIONS

A large number of research studies indicate that proper top-pruning is a beneficial nursery practice. It can benefit nursery managers by increasing both crop value and seedling uniformity. For the consumer or forest landowner, seedlings that have been properly top-pruned will have a higher RWR and a greater chance of survival. Proper top-pruning increases growth after planting so that after 3 years in the field, there typically is no difference in total height between non-pruned and top-pruned seedlings.

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EFFECT OF DENSITY AND SPACING ON SEEDLING UNIFORMITY IN A LOBLOLLY PINE NURSERY

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Abstract—We conducted a nursery study to determine the effects of spacing and arrangement on size and uniformity (variance) of loblolly pine (*Pinus taeda* L.) seedlings. Three spacings and two arrangements were simulated. Sections of nursery bed were thinned to 170 and 200 seedlings per square meter by either removing seedlings within each drill or by a combination of removing seedlings from within drills and removing the third and sixth drills in the bed. A control, unthinned treatment (approximately 320 seedlings per square meter) was also included. Standard nursery practices, including top-pruning and root-pruning, were followed. On October 21, 1996, seedlings were lifted by drill, and the following measurements were made: shoot length, root length, and root collar diameter. Oven-dry biomass of roots and shoots were measured on a subsample from each drill. Data were subjected to analysis of variance to determine treatment differences in means of measured variables. The effect of drill on seedling variables was determined. A one-tailed F test was used to test the alternative hypothesis that the six-drill variances were smaller. Variances of seedling shoot dry weights, root dry weights, and total dry weights were significantly reduced in the six-drill treatments, compared with eight-drill culture at both seedbed densities. Seedling root collar diameters were significantly less variable in the six-drill culture than in the eight-drill culture at the higher density, but not at the lower density. We concluded that six-drill seedling beds significantly reduced variability in seedling size compared to conventional eight-drill beds.

INTRODUCTION

Seedling uniformity is a significant factor influencing the quality of seedlings in loblolly pine nursery operations. Seedlings with highly variable root collar diameters and weights are difficult to pack, inefficient to plant, and have larger percentages of culls. These factors are also strongly correlated with survival and growth of seedlings after planting. Seedling size has been shown to strongly influence post-planting survival and growth in loblolly pine (South 1992, Switzer and Nelson 1963). Producing seedlings with small, predictable ranges of these variables is an important goal of nursery management. As part of a larger seedling quality project, we devised an experiment to test the hypothesis that seedlings grown in three pairs of drills spaced at 15 centimeters (cm) within the pair and 30 cm between pairs would have less variable size distributions than those grown in eight drills spaced at 15 cm, but have similar mean seedling sizes. We tested this hypothesis at two densities and compared to an operational check.

METHODS AND MATERIALS

Research was conducted during the 1996 growing season at the John F. Sisley Nursery in Buena Vista, GA. Two densities and two arrangements were simulated by thinning within drills and by removing drills 3 and 6 (of 8 drills). On June 6, 1996, 1.5-meter long [1.9 square meter (m^2)] sections of nursery bed were thinned to 170 and 200 seedlings per m^2 by either removing seedlings within each drill or by a combination of removing seedlings from within drills and removing the third and sixth drills in the bed. Original drill spacing was 15 cm; spacing between drills 2 and 4 and between drills 5 and 7 after removal of drills 3 and 6 was 30 cm. A control, unthinned treatment (approximately 320 seedlings per m^2) was included as an operational check. Treatments were applied in three randomized complete blocks. All plots were installed on beds sown with a single, half-sibling family to control for genetic effects. Operational nursery practices including fertilization, top-pruning, and root-pruning were followed. A schedule of these treatments is presented in table 1.

Between October 21 and 25, 1996 all seedlings within the interior 60 cm of each plot were lifted, and the following measurements were made: shoot length, root length, and root collar diameter. Drill identity was maintained throughout the data collection. Oven-dry biomass of roots and shoots were determined on four, systematically selected seedlings from each drill in each plot. Separate means were calculated for each drill. The effect of drill on seedling

Table 1—Cultural treatments followed at Sisley Nursery during 1996 growing season

Treatment	Rate	Date
Sowing	—	Apr. 9
Undercutting	—	Aug. 6
Undercutting	—	Sept. 19
Lateral root pruning	—	Aug. 21
Top clipping	—	July 23
Top clipping	—	Aug. 20
Top clipping	—	Sept. 25
Ammonium sulfate	22.5 kg/ha N	Jun. 3
10-10-10	14 kg/ha N	Jun. 19
Urea ammonium nitrate	28.1 kg/ha N	Jun. 24
Urea ammonium nitrate	28.1 kg/ha N	July 17
Urea ammonium nitrate	28.1 kg/ha N	Aug. 5
Ammonium sulfate	22.5 kg/ha N	Aug. 28
Urea ammonium nitrate	28.1 kg/ha N	Sept. 9
10-10-10	14 kg/ha N	Sept. 9

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variables was determined. Data were subjected to analysis of variance to determine treatment differences in means of measured variables. One-tailed F tests were done to test the alternative hypotheses that the six-drill treatments had lower overall root collar diameter (RCD), shoot dry weight, root dry weight, and seedling dry weight variances.

RESULTS

Treatment means are presented in table 2. Root collar diameter and seedling biomass were negatively related to bed density, as expected. Drill arrangement had no significant effect on seedling biomass within a density, and only a minor effect on root collar diameter at the lower density level. Shoot and root length varied significantly among treatments, but no clear patterns were evident. Magnitudes of the differences in shoot length were not considered biologically significant.

Seedling weight variance was significantly reduced by the six-drill treatment at both bed densities, and RCD variance was significantly reduced at the 200 seedlings per m^2 density but not at 170 seedlings per m^2. Both shoot dry weight and root dry weight variances were similarly affected by the treatments (table 3).

Table 2—Means[a] of seedling variables by treatment measured at the end of the 1996 growing season in the seedling density and spacing uniformity trial

	Treatment[b]				
Variable	8-320	6-200	8-200	6-170	8-170
Density, seedlings/m^2	319	199	202	167	170
Root collar dia., mm	4.3d	5.1c	5.0c	5.3b	5.4a
Seedling dry wt., g	4.0d	5.6bc	5.2c	6.0ab	6.3a
Shoot dry wt., g	3.3c	4.6b	4.3b	5.0a	5.2a
Root dry wt., g	0.7c	1.0ab	0.9b	1.0ab	1.1a
Shoot/root wt. ratio	5.4a	4.7c	5.4a	5.2ab	4.9bc
Shoot length, cm	31.8b	32.0ab	32.1ab	31.2c	32.2a
Root length, cm	16.7c	18.1b	18.0b	18.1b	18.6a

[a] Means in the same row followed by the same letter are n.s.d. according to Duncan's multiple range test, $p<0.05$
[b] Treatments are designated by [number of drills]-[target density].

Table 3—Variances and F statistics for one-tailed F tests of homogeneity of variance in the seedling density and spacing uniformity trial[a]

		Variance			
Variable	Density (trees/m^2)	8-drill	6-drill	F	P>F
Root collar diameter	200	0.90	0.67	1.33	0.01
Root collar diameter	170	0.71	0.77	0.92	n.s.
Seedling dry weight	200	3.97	2.89	1.37	0.10
Seedling dry weight	170	5.18	3.32	1.56	0.05
Shoot dry weight	200	2.90	1.91	1.52	0.05
Shoot dry weight	170	3.52	2.42	1.46	0.05
Root dry weight	200	0.49	0.18	20.	0.01
Root dry weight	170	0.21	0.10	2.01	0.01

[a] Degrees of freedom for the F tests were 450/443 for root collar diameter at 200 seedlings per square meter, 379/371 for root collar diameter at 170 seedlings per square meter, and 95/71 for the other variables and densities.

DISCUSSION AND CONCLUSIONS

Significant reductions in the variability of seedling RCD and dry weight were achieved by growing the trees in six unequally spaced drills as compared with eight equally spaced drills. We attribute this effect to the reduction in the variability of the competitive environment encountered by each seedling. Each seedling has two types of competitors—those in the same drill and those in the adjacent drills. For the seedlings in the outer two drills, adjacent-drill competition is, of course, restricted to one side, while inner-drill seedlings face adjacent-drill competition on both sides. In the six-drill beds, adjacent-drill competition is reduced for the inner drill seedlings by removing drills 3 and 6. Although the competitive environment is not identical for inner and outer drills under the six-drill regime, it is much more similar.

We concluded from this study that it is possible to reduce within-bed seedling size variability without changing seedling size by manipulating seedling arrangement. Further research is needed to determine whether the six-drill arrangement will reduce seedling variability at higher bed densities.

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TOPWORKING GENETIC SELECTIONS TO REDUCE THE BREEDING CYCLE IN LOBLOLLY PINE

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Abstract—Genetic improvement of forest trees is a slow process because many tree species have long generation intervals. Even though forest geneticists can make early evaluations in progeny tests, the new genetic selections cannot be bred until adequate male and female strobili are produced on the selected genotypes. This time period is typically 4 to 6 years, or even longer, after the selections are grafted into a seed orchard or clone bank. The topworking procedure described reduces the generation interval in loblolly pine (*Pinus taeda L.*) and, thus, reduces the breeding cycle for the species. In this study, 200 selected scions from progeny tests were grafted into the crowns of reproductively mature loblolly pines in an operational seed orchard. One-half of the grafts were made in the upper crown and one-half were made in the lower crown. One year after grafting, 55 percent of the surviving topworked scions produced female strobili in the upper crown, and 33 percent of similar scions produced pollen in the lower crown. Two years after grafting, the total number of female cones was 875 on 96 live branches in the upper crowns. In the lower crowns, no female strobili were produced in either year but 91 percent of the live grafts produced pollen strobili 2 years after grafting. The number of pollen clusters on the surviving grafts in both the upper and lower crowns increased from 99 in year 1 to 1,394 in year 2. Topworking is an effective and inexpensive procedure and has the potential to greatly accelerate the tree improvement process by reducing the breeding cycle in loblolly pine.

INTRODUCTION

Tree improvement programs in loblolly pine (*Pinus taeda L.*) use a recurrent selection strategy in which new selections are made among individuals in the best performing families based on progeny field trials. Crosses among the selections evaluate the genetic performance of each selection and produce the next generation of pedigreed individuals for recurring selections. Plant breeders who work with annual crops can complete a breeding cycle in the growing season after selection. Unfortunately, this process is much slower in forest trees and is the major deterrent to accelerated breeding programs.

Once selections are made, vegetative propagation is used to move the genotype from the field site to a breeding orchard or clone bank location. After the genetic tests are completed, the best of the new selections are sent to a seed orchard. This process requires valuable time between selection and establishment in a seed orchard. Tree breeders seek to shorten the breeding cycle by reducing the generation interval, i.e., the time required to produce adequate pollen and female strobili and complete cross-pollinations among selected genotypes for genetic testing.

To reduce the generation interval in forest trees, indoor breeding facilities were developed. Large containers with grafted trees were grown in a high-ceiling greenhouse environment. Water stress and gibberellic acid induced the young grafts to produce both female and male clones to use in the breeding program (Greenwood and others 1986). Using this method, selection preceded seed production by at least 5 years.

Burris and others (1991) reduced indoor breeding schedule by 1 year when they applied flower inductive treatments in the same year as grafting. The breeding cycle could not be reduced further because pollen was unavailable on indoor-grown pines until 26 months after grafting. A surrogate pollen production method produced pollen in year 1 (Bramlett and others 1995). Scions from newly selected genotypes were grafted into the lower crown on heavy pollen-producing trees in a production seed orchard. Pollen strobili, present 13 months after grafting, provided adequate pollen for breeding four of five grafted genotypes.

Similar experiments produced female strobili on newly selected scions when grafted into the upper crown of seed orchard trees. Bramlett and Burris (1995) reported that scions from seedlings age 1 to 5 years produced female strobili 1 year after grafting into reproductively mature loblolly pines. This paper presents the results of second-year growth and flower initiation on scions grafted into the upper and lower crowns of reproductively mature loblolly pines.

MATERIALS AND METHODS

Scions were collected from trees that ranged in age from 1 to 5 years. Scions from each age class were part of a 12-clone, first-generation mix of trees used as a check lot in the Weyerhaeuser Company's progeny tests. Because the mix had an equal number of seedlings from each clone, each age class included similar but not identical genetic material. Individual trees selected for scion collection could not be identified by individual family, but the composite sample represented a minimum of 15 trees from the same genetic source. Scions from age classes 2 to 5 were collected from progeny test sites. Scions from age class 1 were collected from seedlings growing in a nursery bed.

Four clones were selected as receptor clones in the Weyerhaeuser Company's second-generation loblolly pine

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seed orchard at Lyons, GA. Good female and pollen strobili producers, these clones had been established in the seed orchard in 1984. The seed orchard is intensively managed by fertilizing, mowing, applying herbicides, and spraying for insect pests.

Scions were grafted in February 1994. The scion was prepared by removing all needles and making longitudinal cuts to form a wedge starting just below the terminal bud. Ten receptor (interstocks) branches were chosen, five in the upper crown and five in the lower crown. A longitudinal cut was made just below the terminal bud of each interstock branch, reaching into the pith area and continuing downward for another 3 to 4 inches. The prepared scion was inserted into this slit. After the left side of the scion cambium was matched with the cambium layer of the interstock, the scion was secured in place with a rubber budding strip. Hot wax (175 to 200 oF) was applied to the completed graft. Two to four weeks after new shoot growth emerged through the wax, the interstock branch tip and the rubber budding strip were removed.

A split-plot experimental design was used with the receptor clones considered blocks and scion age the treatment variable. An individual ramet of the receptor clone was the whole plot, and crown location was the split plot. Five individual branches were observations within the subplots. The receptor clone was considered a random variable, and treatment (age class) a fixed variable. Survival of scions, shoot elongation, and the number of female and pollen strobili in the upper and lower crown locations were recorded in March 1995 and 1996.

The data were analyzed using the SAS (SAS Institute, Cary, NC) procedure for mixed models. Contrasts were computed for all possible comparisons (10) of the five scion age classes for the upper and lower crown levels. For each response variable tested, mean separation was computed using the 5 percent level of probability for the comparison-wise error rate.

RESULTS AND DISCUSSION

The pronounced effect of crown location on shoot growth, observed in the first year after grafting, became even more evident in the second year after grafting. Surviving lower crown grafts increased in shoot length from an average of 5.4 inches to an average of 14.8 inches after the second growing season (table 1). Scions grafted in the upper crown produced branches that were much larger in both years. In year 1, shoot growth averaged 14.6 inches. In year 2, shoot length increased to an average of 33.0 inches. The crown location effect on shoot growth was statistically significant at the 0.01 level of probability in both the first and second year after grafting. Differences were not statistically significant among the mean values for shoot growth within age classes in either the upper or lower crowns.

The increased growth of grafted branches in the upper crowns also increased the number of second order branches and, subsequently, the number of potential flower producing locations. Although the total number of branches was not recorded in the second year, the upper crown grafts had much larger branches and a more complex branching order than lower crown grafts. Grafted scions in

Table 1—Shoot growth on 1- to 5-year-old scions 2 years after grafting into mature loblolly pines

Receptor clone	Crown level	Scion age (years) 1	2	3	4	5	Mean
		- - - - - - - - Inches	- - - - - - - -				
24	Lower	10.3	12.2	15.6	16.6	14.0	14.1
12		16.6	23.2	14.5	18.4	9.7	16.9
66		17.0	12.5	15.4	14.6	13.4	14.6
10		14.5	14.6	15.6	12.0	13.1	13.9
Mean[a]		15.0a	15.9a	15.3a	15.4a	12.8a	14.8
24	Upper	31.4	35.4	35.4	32.4	28.4	32.6
12		33.0	39.6	29.8	37.6	24.7	33.8
66		24.4	36.4	38.6	39.8	30.2	33.9
10		30.5	34.2	39.4	17.8	37.0	31.8
Mean[a]		29.8a	36.4a	36.1a	31.9a	30.7a	33.0

[a] Means followed by the same letter are not significantly different at the 0.05 level.

both the upper and lower crowns retained their juvenile foliar appearance in the second year. Needles on grafts were smaller in length and diameter than mature foliage of the interstock. Needles on grafts also showed differential dormant season coloration, with grafts having more yellow foliage, typical of juvenile trees. In addition, the dormant buds of grafted scions were smaller in diameter and length than comparative buds on the interstock, and the shoots of grafts elongated more growth cycles than similar branches on the interstocks.

Female Strobili Production

The number of female strobili produced in the upper crowns increased the second year after grafting. In the first year, 247 female strobili were initiated on the 96 live grafts. In the second year, 875 female strobili were produced on the grafts, averaging 9.1 strobili per live graft (table 2). Female strobili were not produced on any branches grafted in the lower crowns. This pattern reflects the normal distribution of female strobili within the crown of loblolly pine. The mean number of female strobili was significantly larger on 4-year-old scions than on 1-year-old or 5-year-old scions. The observation that 4-year-old scions have more strobili than 5-year-old scions may be a result of different clonal material.

Pollen Clusters

One year after grafting, no pollen clusters were initiated on scions from 1-year-old trees grafted in either the upper or lower crowns (Bramlett and Burris 1995). However, 2 years after grafting, scions from 1-year-old seedlings produced pollen in both upper and lower crowns and scions from all other age classes produced abundant pollen (table 3). In the lower crowns, 88 percent of the live grafts produced pollen 2 years after grafting; in the upper crowns, 96 percent produced pollen. Pollen production dramatically increased in the upper crowns from year 1 with 43, to year 2 with 1,101 clusters or an average of 11.5 pollen clusters per live graft. This large increase probably resulted from the large increase in shoot growth of grafts in the upper crowns. Grafted branches averaged over 33 in. in length with many side shoots and multiple low order branches, which are optimum sites for pollen initiation. In addition, in the 2 years since grafting, the growth of the tree crowns has increased and the former upper crowns are now more correctly classified as midcrowns. The midcrown is within the zone of heavy pollen production on the seed orchard ramets used for interstocks. The difference in pollen production between the lower and upper crowns was statistically significant at the 0.01 level of probability. No statistical differences were noted among mean values for scion ages in the lower crowns. In the upper crowns, 4-year-old scions produced fewer pollen strobili than 2-, 3-, or 5-year-old scions. This result is probably an effect of the specific genotypes used in the study.

CONCLUSIONS AND IMPLICATIONS

Waiting an additional year after topworking new selections into mature loblolly pine crowns apparently increases the number of female strobili and pollen clusters for breeding. Even though this delay would add 1 year to the breeding schedule, fewer grafts would provide enough strobili to complete the breeding cycle.

The 350 percent increase in female strobili production is partly a result of selecting large primary branches for grafting. These branches continued to develop within the tree crowns and increase in size and number of female strobili per graft. These primary branches were also suitable for installing isolation bags for controlled pollination procedures. For efficient tree breeding, a relatively small number of topwork grafts could be made and controlled pollination could begin the second year after grafting. How many grafts are enough for each selection? Based on this study, approximately nine strobili were produced per living graft 2 years after grafting.

Table 2—Female strobili produced after 2 years from five grafts on 1- to 5-year-old scions grafted into the upper crown of mature loblolly pine (no female strobili were produced in the lower crown)

		Scion age (years)					
Receptor clone	Crown level	1	2	3	4	5	Total
		- - - - - - - -	- - - - - - - -	- - - -	Numbers - - - -	- - - - - - - -	- - - - - - - -
24	Upper	27	35	24	37	81	204
12		33	64	26	171	0	294
66		34	90	18	71	12	225
10		2	39	85	13	13	152
Mean[a]		24 b	57 ab	38 ab	73 a	26 b	219
Total		96	228	153	292	106	875

[a] Means followed by the same letter are not significantly different at the 0.05 level.

Therefore, 5 to 10 grafts for every anticipated cross in the mating design should provide adequate female strobili for breeding 2 years after grafting. Of course, grafting success is critical! In this study, 96 percent of attempted grafts were alive in the upper crowns 2 years after grafting; 91 percent in the lower crowns. These results may be exceptional but a success rate of 75 to 80 percent appears achievable. Grafting procedures are basically similar in the crowns and at ground level except for logistics. However, procedures to maintain hot wax in a bucket truck or aerial lift are required to maintain grafting efficiency and to minimize the time and expense of grafting.

These results give the tree breeder another option. If the breeder waits until the second year after grafting, both male and female strobili production increase dramatically. Thus, if the breeder waits until year 2, only a few grafts (5 to 10) in the upper and midcrowns may produce enough pollen and female flowers to complete each cross.

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Table 3—Total number of pollen clusters produced 2 years after grafting in the lower and upper crown of topworked, mature loblolly pines

Receptor clone	Crown level	Scion age (years) 1	2	3	4	5	Total
		Numbers					
24	Lower	2	8	15	23	10	58
12		17	9	17	28	5	76
66		1	19	22	25	21	88
10		4	19	14	21	13	71
Mean[a]		6a	14a	17a	24a	12a	73
Total		24	55	68	97	49	293
24	Upper	18	46	62	29	58	213
12		42	106	38	82	22	290
66		26	122	46	44	87	325
10		37	39	103	31	63	273
Mean[a]		31b	78ab	62ab	46b	58ab	275
Total		123	313	549	186	230	1101

[a] Means followed by the same letter are not significantly different at the 0.05 level.