Undercutting in Loblolly and White Pine Seedbeds

Thomas A. Dierauf [1]

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Abstract — In seven studies installed in six different years, undercutting loblolly pine seedlings has had little effect on survival for our sandy New Kent and Sussex nurseries. For six studies, survival improvement ranged from +2 to -1 percentage points and averaged only one percentage point. White pine survival, on the other hand, was improved considerably by undercutting. Survival increases ranged from 13 to 20 percentage points for five studies, and averaged 18 points.

INTRODUCTION

We have installed seven undercutting studies in loblolly pine and five in white pine. There were two early studies in loblolly pine, in 1977 and 1982, and the results were published in 1982 and 1988 in Occasional Reports #58 and #72. The other five undercutting studies in loblolly pine and the five studies in white pine were installed between 1988 and 1991. These will soon be published in Occasional Reports #115 and #116. For the proceedings of this conference, I have repeated the information presented in these four occasional reports that deals with study procedures and field results. I have omitted information on the effect on root collar diameter and top length in the seedbed.

LOBLOLLY STUDIES

1977 Study

A study to test the effects of undercutting, lateral root pruning and top clipping was installed in loblolly pine seedbeds at the New Kent Nursery in the summer of 1977. The following seven undercutting treatments were replicated in three different seedbeds (the three seedbeds were in different nursery blocks). Seedbed plots were 20 feet long.

1. Control	not undercut
2. Undercut	Aug. 8
3. "	Aug. 8 & Sept. 1
4. "	Aug. 8, Sept. 1, & Oct. 4
5. "	Sept. 1
6. "	Sept. 1 & Oct. 4
7. "	Oct. 4

Each plot was divided in half to produce two ten-foot-long sub-plots, and each subplot was again divided in half to produce two five-foot- long sub-subplots. Lateral root pruning was done each time undercutting was done. The lateral pruning was done first, with undercutting following immediately. Top clipping was done on half of each subplot (sub-subplot). All top clipping was done on September 1st. The experimental design was, therefore, a split-split-plot with undercutting treatments assigned to main plots, lateral pruning to subplots, and top clipping to sub-sub plots.

The undercutting was done at a depth of about 5 inches, and was followed immediately by irrigation. This worked satisfactorily in a preliminary test of the undercutter when the soil was moist. However, when the first undercutting treatment was applied on August 8th, the soil was drier and looser than it was during the preliminary test (the soils at the New Kent Nursery are loamy sands and sands with typically close to 90 percent sand

[1] Virginia Department of Forestry, Charlottesville, Virginia.

in the topsoil). There were many fissures running across the beds after undercutting, and in one of the three seedbeds, the roots were dragged and the seedlings leaned at about a 45 degree angle after undercutting. The seedlings in all three seedbeds quickly wilted and the terminals drooped. They did not fully recover by the next morning. We learned from this experience and made sure the soil was moist, irrigating if necessary, before undercutting on September 1st and October 4th. No wilting or leaning occurred following these later undercuttings.

Lateral root pruning was done to a depth of 3 to 4 inches, using coulters running midway between each row of seedlings (seedbeds contain eight rows of seedlings and are separated by paths 2 feet wide).

Top clipping was done at a height of 7 inches with hand shears. When the clipping was done on September 1st, the proportion of seedlings clipped on a plot was strongly affected by whether or not the plot had been undercut on August 8th. The August 8th undercutting reduced height growth, so that considerably fewer seedlings were tall enough to be clipped on these plots.

The August 8th undercutting caused scattered seedling mortality in the seedbed in which the seedlings were dragged. Obviously, the soil was too dry when the undercutting was done.

On December 6th, a 3-inch wide (one square foot) sample across the bed was lifted from the central portion of each sub-subplot. It was noticed while lifting the samples that seedlings undercut on August 8th were harder to pull; they had more lateral roots resulting in a denser root system. The September 1st and October 4th undercuttings did not noticeably alter root system morphology.

Seedlings were selected for planting in the field from the same samples that were lifted and measured to evaluate seedbed treatments. Lateral root pruning had no measurable effect in the seedbeds, so lateral pruned and unpruned seedlings were combined for field planting. Therefore, 14 treatments were planted in the field (7 undercutting x 2 top clipping = 14 treatments). There were six samples (from six different sub-subplots) from which to select seedlings for each treatment planted in the field. Representative samples were obtained by taking proportional numbers of seedlings from each diameter class from each of the six samples per treatment. The seedlings were planted on December 14th on a well-drained upland site on the Appomattox-Buckingham State Forest in the central piedmont. The winter of 1977-78 broke records for cold temperatures and the seedlings turned brown, but most of them recovered.

Overall survival for all treatments was 89, 88, and 81 percent after one, two, and three seasons in the field. The big drop between the second and third season was due to girdling by mice, which was not evenly distributed over the plots. Survival after the second season in the field, therefore, is summarized in Table 1. Undercutting and top clipping had no consistent effect on survival.[2]

Table 1. Average survival by treatment after the second season in the field.

Undercutting	Clipped	Not Clipped	Means
1. Not Undercut	88	87	88
2. Aug. 8	83	90	87
3. Aug. 8, Sept. 1	92	93	92
4. Aug. 8, Sept. 1, Oct. 4	95	92	93
5. Sept. 1	92	75	83
6. Sept. 1, Oct. 4	82	88	85
7. Oct. 4	97	77	87
Means	90	86	88

This effect of undercutting and top clipping on height growth is shown in Table 2. After three seasons in the field, undercut seedlings averaged about .4 foot taller than check seedlings[3]. Top clipped seedlings averaged about .1 foot taller than unclipped seedlings, but this difference was not statistically significant.

Table 2. Average height by treatment after three seasons in the field.

Undercutting	Clipped	Not Clipped	Means
1. Not Undercut	4.9	4.5	4.7
2. Aug. 8	5.3	5.0	5.2
3. Aug. 8, Sept. 1	5.0	5.1	5.0
4. Aug. 8, Sept. 1, Oct. 4	5.4	5.0	5.2
5. Sept. 1	4.8	4.8	4.8
6. Sept. 1, Oct. 4	5.2	5.2	5.2
7. Oct. 4	5.4	5.1	5.3
Means	5.1	5.0	5.1

1982 Study

This study was installed at the New Kent Nursery during the summer of 1982. The following undercutting treatments were replicated by 10-foot plots in three different seedbeds, each located in a separate nursery block.

1. Control not undercut
2. Undercut July 20
3. " July 20 & Aug. 19
4. " Jul 20, Aug 19, & Sep 21
5. " Aug. 19
6. " Aug. 19 & Sept. 21
7. " Sept. 21

We attempted to undercut at a depth of about 5 inches, although the actual undercutting depth varied between 4½ and 5½ inches, on all three dates. After the first undercutting, on July 20th, there was a delay of ½ hour for one replication and 2½ hours for the other two replications before irrigation water was applied. In the two replications that went 2½ hours before irrigation, the taller seedlings wilted, and some seedlings were leaning as much as 90 degrees. For the later undercuttings, on August 19th and September 21st, irrigation closely followed undercutting and no wilting occurred. Even after the visible wilting following the August 19th undercutting, no mortality was observed. The seedlings in all the plots were operationally top-clipped on August 11th and September 7th, to an average height of about 8 inches.

On December 17th, we lifted a 6-inch-wide sample (2 square feet) across the bed in the center of each plot. Each sample was counted into three piles as it was lifted, so that seedlings from each drill row were evenly spread over the three piles. One pile was randomly selected for planting. The other two piles were put in storage until January, when root collar diameters were measured and seedlings separated into 1/32nd -inch diameter classes.

Later in the afternoon of the day we lifted the seedlings, seedlings were selected for planting in the field. We had three lots of seedlings from each treatment, one from each seedbed replication (1/3 of the 2 foot square sample lifted from each plot). These three lots, for each treatment, were successively counted into four piles of 20+ seedlings each, which gave us the seedlings we needed for four replications in the field. This sorting procedure ensured that we selected about the same number of seedlings from each seedbed replication for each field replication.

The study was planted on December 21st, in four randomized blocks with a 20 seedling row of each treatment in each block. The site was a gentle upper slope on typical well-drained soil in the

[2] Survival percents were transformed to arc sine and an ANOVA was made. Neither undercutting or top clipping significantly affected survival.

[3] An ANOVA was made of mean heights after three seasons in the field. The effect of undercutting was significant (probability of a larger F = .036), but top clipping and the interaction of undercutting and top clipping were not.

central piedmont.

Average survival dropped only one percentage point between the end of the first and third seasons. After three seasons, average survival for the six undercutting treatments was less than one percentage point higher than for the control (Table 3). The only statistically significant difference is between the July 20th and August 19th undercutting treatments (Treatments 2 and 5).

Table 3. Average survival and height after three seasons in the field.

Treatment	Survival Percent	Height in Feet
1. Not Undercut	91ab	5.4b
2. July 20	99a	5.4b
3. July 20, Aug. 19	94ab	5.9a
4. July 20, Aug. 19, Sept. 21	89ab	5.6ab
5. Aug. 19	89b	5.3b
6. Aug. 19, Sept. 21	91ab	5.4b
7. Sept. 21	91ab	5.4b
Means	92	5.5

Survival percents were transformed to arc sine and an analysis of variance carried out. The overall F for treatments was not statistically significant (probability of a larger F = .355). Duncan's New Multiple Range Test was used to test for differences among individual treatments, and survival percents in Table 3 not followed by the same letter are significantly different at the 0.05 level.

After three seasons in the field, seedlings from the six undercutting treatments averaged .1 feet taller than seedlings that were not undercut (Table 3).

1988 Study

Seedlings were undercut four times on the following dates:

Sussex	**New Kent**
July 27	August 1
August 19	August 22
September 16	September 12
October 5	October 5

Undercutting was applied to a 20-foot-long section of seedbed in four widely separated seedbeds at each nursery. We used a home-made, stationary blade for the undercuttings. The target depth was 5½ inches for all undercutting. The last three feet of each 20-foot-long undercut plot was laterally pruned using a flat-blade spade to cut straight down midway between each drill row. Lateral pruning was done just before undercutting. All plots were irrigated for an hour before pruning and again for one to two hours after pruning to prevent, or at least minimize, wilting.

Seedlings were lifted on March 6th at New Kent and March 13th at Sussex. We lifted a 1½-foot-wide sample across the bed, from the center of each 3-foot plot that was both undercut and laterally pruned. The sample was taken from drill rows two through seven. A short distance past the undercutting plot, we lifted a comparable sample of unpruned check seedlings.

We sorted through the seedlings from each sample (two treatments from each of eight seedbeds) and picked out all seedlings between 4.5 and 6.5/32-inch root collar diameter. Then we counted these into piles of ten seedlings each and randomly selected two piles of ten to combine for a 20 seedling row in the field. The seedlings were planted on the Appomattox-Buckingham State Forest by seedbed location, with the two treatments from each seedbed location (check and root pruned) randomly assigned to each of eight blocks.

Survival didn't change between age one and age three, and root pruned seedlings survived 2.5 percentage points better than unpruned seedlings and were .27 feet taller at age three (Table 4). The survival difference was not statistically significant, but the height difference at age three was

Table 4. Average survival at age one, two, and three and average height at age three.

	Survival at Age 1	2	3	Height at Age 3
Check	95.6	95.6	95.6	5.12
Pruned	98.1	98.1	98.1	5.39

(probability of a larger F = .173 and .032 respectively).

1989 STUDIES

In 1989, we installed two studies, a main study and a pilot study, installed at both nurseries, using a recently purchased Summit undercutter.

1989 Main Study

Seedlings were undercut once, twice, or four times, and for the two and four cut treatments, we undercut at either a constant or increasing depth, giving a total of seven treatments:

1. Undercut once, in July, at 3-inch depth
2. Undercut once, in October, at 5-inch depth
3. Undercut twice, in July and September, at 3- and 5-inch depths
4. Undercut twice, in July and September, at 5-inch depths
5. Undercut four times; in July, August, September, and October; at 3-, 4-, 5-, and 5-inch depths
6. Undercut four times; in July, August, September, and October; at 5-inch depths
7. Check, not undercut.

The actual undercutting dates were:

Sussex	New Kent
July 24	July 26
August 15	August 16
September 13	September 14
October 10	October 12

Undercutting treatments were applied to entire beds, using the seven interior beds of two nine-bed sections at Sussex and one nine-bed section at New Kent. These three sections provided three replications of the seven treatments.

Lateral pruning was done by hand right after the undercutting, using a flat-blade spade pushed straight down midway between the drill rows and outside the outer drill rows. Lateral pruning was done in three plots, each two feet long, within each undercut bed.

Seedbeds were irrigated before and after undercutting. Our intention was to prevent wilting, and we were generally successful, although we had some slight wilting at times.

We lifted the seedlings at Sussex on December 5th, lifting a 4-square-foot sample (one foot wide across the bed) from each of the three lateral pruning plots in each seedbed. The seedlings were kept in cold storage until December 21st, when they were separated by root collar diameter. Small seedlings (below 4/32) were discarded, and proportional numbers of seedlings from each diameter class from each of the three samples were selected for four 20-seedling rows in the field. This was done separately for each of the seven treatments of each of the two seedbed replications.

The seedlings at New Kent could not be lifted until January 8th, because the seedbeds had been frozen continuously since early in December. We measured and selected the seedlings for planting the same day, following the same procedures in lifting, measuring, and selecting seedlings as we did at Sussex.

The seedlings were planted on the Appomattox-Buckingham State Forest in the central piedmont of Virginia on January 9th. We installed four randomized blocks, with a 20-seedling row of each of the seven treatments from each of the three seedbed replications in each block, for a total of 1,680 seedlings.

After one season in the field, average survival among the six root pruning treatments ranged from 97.1 to 98.8 percent while survival of unpruned check seedlings was 96.2 percent (Table 5). After three

seasons, survival ranged from 94.5 to 96.7 among root pruned treatments and was 91.2 for check seedlings. Between the first and third season, cronartium fusiform killed 26 seedlings, 1.5 percent, and this mortality was not evenly distributed over the seven treatments (Table 5). Treatments involving four prunings and the check treatment suffered the most mortality from fusiform, which should be coincidental and not related to treatments.

An analysis of variance was performed on average survival percent at age three, after transforming to arc sine percent. The main effects of root pruning and seedbed location, and their interaction, were not significant (probability of a larger F=.37, .08, and .51 respectively). Orthogonal comparisons were made among root pruning treatments, and none were significant. The comparison of the check with the average of the six root pruning treatments came close (probability of a larger F=.053). If the effect of the root pruning treatments are based on survival after one season, which may be more realistic considering the uneven mortality caused by rust; the improvement from root pruning is considerably less, 1.7 versus 4.3 percentage points (Table 5).

1989 Pilot Study

We installed some small plots to see what might happen if we started undercutting in late June, when the seedlings were only two or three inches tall. We undercut a 20 foot section of seedbed at Sussex at a depth of about 1.5 inches on June 20th. Undercutting was repeated on July 26th at 4 inches, August 15th at 5 inches, September 13th at 4.5 inches, and finally a fifth undercutting was done on October 11th, at 5 inches. A small plot was lateral pruned by hand as in the main study.

We undercut a 20 foot section in each of two seedbeds, side by side, at New Kent, on June 26th at a depth of 3 inches. One bed was undercut a total of five times and the other three times. Small lateral pruning plots were installed. Pruning dates and depths were July 26th at 4 inches, August 16th at 5 inches, September 14th at 5 inches, and October 12th at 5 inches. Lateral pruning was done immediately before undercutting.

Samples were lifted on the same dates and seedlings were selected for planting following the same procedures as for the main study. The seedlings were planted on January 12th adjacent to the main study, in three randomized blocks, planting a 20-seedling row of both pruned and unpruned seedlings from each seedbed, for a total of 18 rows.

Survival after one and three seasons and average height after three seasons are shown in Table 6.

Compared to the main study, unpruned control seedlings survived about the same in both studies (94.4 percent in the pilot study versus 96.2 or 91.2 in the main study after one or three years). However, the root pruned

Table 5. Average survival at age one and three, mortality caused by Fusiform rust between age one and three, and average height at age three.

Treatment	Survival Percent		Mortality from Fusiform	Height at Age 3
	Age 1	Age 3		
1. July, 3"	97.5	94.6	1.7	5.8
2. Oct., 5"	97.9	96.7	.8	5.8
3. July & Sept., 3 & 5"	98.3	95.4	1.2	5.6
4. July & Sept., 5"	98.8	96.2	.4	5.6
5. July, Aug., Sept., Oct.; 3, 4, 5, & 5"	97.9	95.8	2.1	5.8
6. July, Aug., Sept., Oct.; 5"	97.1	94.5	2.1	5.6
7. Check	96.2	91.2	2.5	5.6

seedlings survived better in the pilot study, 100 percent versus 97.9 or 95.5 in the main study after one or three years. This suggests that starting undercutting about a month earlier than normally done, when the seedling are still very small, might improve survival. There would be risks in starting this early, because root systems have not yet grown enough to hold the soil together, and the beds could break up badly.

Table 6. Average survival percent at age one and three and average height (in feet) at age three.

Nursery Treatment	Survival Percent		Height
	Age 1	Age 3	Age 3
Sussex, 5 cuts starting at 1½"	100	100	5.8
Sussex, Check	100	95.0	5.7
New Kent, 5 cuts starting at 3"	100	100	5.7
New Kent, Check	91.7	91.7	5.6
New Kent, 3 cuts starting at 3"	100	100	5.9
New Kent, Check	96.7	96.7	5.4

1990 Study

In addition to the Summit undercutter that we purchased and used for last year's study, we purchased a wrenching attachment for the undercutter and a Summit lateral pruner. We used all of these in this year's study. Identical studies were installed at New Kent and Sussex:

1. Undercut twice, in early August and late September, at 3- and 4.5-inch depths

2. Undercut twice, in early August and late September, both times at 4.5-inch depths

3. Undercut once, in early August, at 4.5-inch depth and then wrenched in late September at 4.5 inches

4. Undercut four times; in early August, late August, late September, and late October; at 3-, 4-, 4.5-, and 4.5-inch depths

5. Undercut four times; in early August, late August, late September, and late October; at 4.5-inch depths

6. Undercut once, in early August, at 4.5-inch depth and then wrenched three times in late August, late September, and late October at 4.5 inches

7. Check, not undercut.

All root pruning treatments included lateral pruning, done just after undercutting or wrenching. Beds were irrigated before (if necessary) and after pruning to avoid (or at least minimize) wilting. Treatments were applied to full-length beds in three different sections at both New Kent and Sussex, 42 beds in all, counting the control beds.

Seedlings were lifted on December 3rd and 4th at New Kent and December 10th at Sussex. We lifted three samples from each seedbed, each sample 3 inches wide across the bed for a one-square- foot sample. The total number of samples lifted was 126: three samples per seedbed times seven treatment beds per section times six sections.

Seedlings were separated by root collar diameter, keeping each sample separate. New Kent seedling were measured on December 4th and Sussex seedlings

The actual undercutting dates were:

Sussex		**New Kent**	
Two Times	Four Times	Two Times	Four Times
August 1 & 3	August 1 & 3	August 7 & 8	August 7 & 8
---	August 29	---	August 30
September 26	September 26	September 27	September 27
---	October 24	---	October 26

on December 11th. Seedlings smaller than 3.5/32nds were discarded, and from the remaining seedlings, proportional numbers of seedlings were randomly taken from each diameter class from each of the nine samples (3 samples from each of 3 sections) to obtain 80 seedlings (enough for four 20-seedling rows) from each undercutting treatment from each nursery. To prevent roots from drying while all of this measuring and counting was done, we misted the roots with water frequently and kept them covered with plastic.

The seedlings were planted on December 13th on the Appomattox-Buckingham State Forest. We installed four randomized blocks, with a 20-seedling row of each treatment form each nursery in each block, for a total of 1,120 seedlings.

Survival changed very little between age one and age three (Table 7). Only two seedlings, in the entire study, died during the second season, and one seedling during the third season. An analysis of variance was performed on average survival percent at age three, after transforming to arc sine percent. The main effects of root pruning and nursery, and their interaction, were not significant (probability of a larger F = .99, .34, and .89 respectively). Orthogonal comparisons were made among treatments and none were significant. The one that came closest to being significant was the interaction between nurseries and two versus four prunings (probability of a larger F = .33).

Root pruning did improve height growth slightly, primarily for Sussex seedlings (Table 7). The average difference between pruned (all six treatments combined) and control seedlings at age three was 6.97 versus 6.89 for a difference of .08 feet at New Kent and 7.38 versus 7.00 for difference of .38 feet at Sussex. An analysis of variance was performed on average heights at age three. The main effect of root pruning was not significant (probability of a larger F = .35), but the main effect of nursery was (probability of a larger F = .003). The interaction of root pruning and nursery was not significant (probability of a larger F = .58). Orthogonal comparisons were made among treatments, and the only significant one was again the overall comparison of New Kent and Sussex seedlings (probability of a larger F = .003).

1991 Study

This was a comparison of operationally root pruned and unpruned seedlings at the Sussex Nursery. Four sections were involved, and eight of the nine beds in each section were undercut and lateral pruned on August 21 and October 21. The center bed of each section was left unpruned as a

Table 7. Average survival at age one and three and average height at age three.

	New Kent			Sussex		
	Survival		Height at	Survival		Height at
Treatment	Age 1	Age 3	Age 3	Age 1	Age 3	Age 3
1. Pruned 2 times, increasing	91.2	91.2	7.0	95.0	95.0	7.2
2. Pruned 2 times, constant	92.5	92.5	7.2	96.0	94.8	7.2
3. Pruned 2 times, wrenched	93.8	92.5	7.2	93.8	93.8	7.7
4. Pruned 4 times, increasing	90.0	90.0	6.9	96.2	96.2	7.4
5. Pruned 4 times, constant	90.0	90.0	6.7	96.2	96.2	7.3
6. Pruned 4 times, wrenched	95.0	95.0	6.9	95.0	95.0	7.5
7. Control	93.5	93.5	6.9	95.0	93.8	7.0
Means	92.3	92.1	7.0	95.3	95.0	7.3

check. The seedbeds were irrigated before and after pruning to avoid wilting.

Samples were lifted on January 2, 1992. We lifted a total of 16 samples, each sample 6 inches wide across the bed for 2 square feet per sample. In each of the four sections, we lifted two samples from the unpruned center bed and a single sample from each of the pruned beds on either side. Check and pruned samples were paired.

Seedlings for a 20-seedling row in the field were randomly selected from each of the 16 samples. The seedlings from each paired sample, a pruned and a check, were used to plant a replication in the field, for a total of eight replications. The seedlings were planted on January 6th on the Appomattox-Buckingham State Forest.

Survival after one and two seasons in the field and average height after two seasons is presented in Table 8. Analyses of variance were performed on second year survival percents (after transforming to arc sine percent) and second year heights. Neither difference was statistically significant (probability of a larger F = .346 and .134 respectively).

WHITE PINE STUDIES

1988 Study

This was a small pilot study. We used a flat-blade spade to do the root pruning in small seedbed plots about 2 feet long. We angled the spade, starting midway between drill rows, so as to sever the tap roots at a depth of 5 to 6 inches. The cutting was done from both sides of each drill row. We installed two pairs of plots at each nursery, with the plots of each pair being only a few feet apart. One plot of each pair was root pruned about every three weeks and the other about every four weeks, starting in early June. We made a total of six prunings for the plots root pruned about every three weeks and five prunings for those pruned about every four weeks.

If the soil was dry, we irrigated before pruning, and we always irrigated after pruning. Our objective was to prevent wilting following the pruning.

We lifted the seedlings on January 12th at New Kent and February 22nd at Sussex. Unpruned check seedlings were lifted adjacent to each pruning plot, starting about 6 inches beyond the point where the root pruning stopped.

Root collar diameters were measured and seedlings separated by 1/32nd -inch diameter classes. The New Kent seedlings were measured on February 2nd and the Sussex seedlings on February 27th. Seedlings for planting in the field were selected proportional to the number of seedlings in each diameter class, discarding all seedlings less than 3/32nds - inch diameter. Forty seedlings were selected from each sample, enough for two rows of seedlings in the field.

Two planting installations were made, one on the Appomattox-Buckingham State Forest in the central Piedmont of Virginia and the other on the Page Nelson Tract in Botetourt County, in the Ridge and Valley area of Virginia. Seedlings were planted on March 2nd on the Appomattox-Buckingham State Forest and on April 6th in Botetourt County.

Root pruning increased survival by about 20 percentage points. Three and four week pruning frequencies gave similar results (Table 9). Analyses of variance were performed on average survival at age three, after transforming to arc sine percent. Separate analyses were performed for the Appomattox-Buckingham State Forest and Botetourt County installations. Root pruning im-

Table 8. Average survival at age one and two and average height at age two.

	Survival Percent		Height in Feet
	Age 1	Age 2	Age 2
Pruned	96.2	95.6	3.68
Check	98.1	96.9	3.53

proved survival significantly at both locations (probability of a larger F = .004 and .002 at Buckingham and Botetourt respectively). Seedlings pruned every four weeks rather than every three weeks survived slightly better at both locations, but the differences were not statistically significant. Survival in Botetourt County averaged 23 points better than at the state forest. Root pruning significantly increased average height at age three at Buckingham (probability of a larger F = .006), but had no effect in Botetourt (Table 9).

1989 Study

Seedlings were undercut once, three times, or five times. For the three and five cut treatments, we undercut at either a constant or increasing depth, giving a total of seven treatments:

1. Undercut once, in June, at 3-inch depth
2. Undercut once, in October, at 5-inch depth
3. Undercut three times, in June, August, and October, at 5-inch depth
4. Undercut three times, in June, August, and October, at 3-, 4-, and 5-inch depths
5. Undercut five times, in June, July, August, September, and October, at 5-inch depth
6. Undercut five times, in June, July, August, September, and October, at 3-. 4-, 5-, 5-, and 5-inch depths
7. Control, not undercut.

The actual undercutting dates were:

Sussex	**New Kent**
June 20	June 26
July 24	July 26
August 15	August 16
September 13	September 14
October 10	October 12

Undercutting treatments were applied to entire seedbeds using the Summit undercutter. The seven interior beds of two nine-bed sections, one at Sussex and one at New Kent, provided two replications of the seven treatments. Lateral pruning was done by hand after undercutting, using a flat-blade spade pushed straight down, midway between the drill rows and outside the outer drill rows. Lateral pruning was done in three plots, each 3 feet long, within each undercut bed. Seedbeds were irrigated before and after undercutting in order to prevent wilting.

Seedlings were lifted at Sussex on January 15th and at New Kent on January 18th. We lifted three samples from each seedbed, each sample 6 inches wide for a 2-square-foot sample. These samples were lifted from the center of the three small lateral pruning plots in each seedbed. The seedlings in each sample were measured and separated by root collar diameter. We measured the Sussex seedlings on January 17th and 18th and the New Kent seedlings on January 24th and 25th. Seedlings below 4.5/32^{nds} inch were discarded, and proportional numbers of seedlings from each diameter class of the three samples from each seedbed were selected for four 20-seedling

Table 9. Average survival at age one and three and average height (in feet) at age three.

Treatment	Appomattox-Buckingham State Forest			Botetourt County		
	Survival		Height at Age 3	Survival		Height at Age 3
	Age 1	Age 3		Age 1	Age 3	
3 weeks, pruned	71.2	65.0	3.0	91.0	87.0	1.9
3 weeks, control	52.5	45.0	2.7	74.2	67.5	1.9
4 weeks, pruned	70.0	67.5	3.1	93.2	92.0	2.1
4 weeks, control	51.2	47.5	2.6	77.8	71.2	2.0

rows in the field. This was done separately for each of the seven treatments of each of the two seedbed replications.

The seedlings were planted on January 26th on the Appomattox-Buckingham State Forest. We installed four randomized blocks, with a 20-seedling row of each of the seven treatments from each nursery planted in each block, for a total of 56 rows and 1,120 seedlings.

The New Kent seedlings survived and grew better than the Sussex seedlings (Table 10). Root pruning, combining the six different root pruning treatments, increased survival by 32 percentage points for the Sussex seedlings (74.8 versus 42.5) and 7 percentage points for the New Kent seedlings (80.6 versus 73.8). In an analysis of variance, after transforming to arc sine percent, the main effect of pruning and the difference between nurseries were both significant (probability of a larger F = .004 and .002 respectively). Orthogonal comparisons were made, and the only significant comparison was between the average of all six pruning treatments and the control (probability of a larger F = .00004). Increasing the number of cuts and varying pruning depth did not significantly affect survival. When results from the New Kent seedlings were analyzed separately, root pruning did not significantly improve survival (for the comparison between the average of all six pruning treatments and the control, the probability of a larger F = .21).

Height growth was improved by root pruning the Sussex seedlings, but not the New Kent seedlings (Table 10). In an analysis of variance, the height difference at age three between the Sussex and New Kent seedlings was statistically significant (probability of a larger F = .00005).

1990 Main Study

This year we started undercutting much earlier than we had in 1988 and 1989. One treatment started soon after the seedlings had resumed growth in the spring, on March 28th, at an undercutting depth of 2 inches. Thereafter, undercutting was done every five weeks, ending on October 24th, for a total of seven cuts. Lateral pruning was done immediately after each undercutting, using the Summit lateral pruner. As last year, we used the Summit undercutter. Two additional undercutting treatments were started on May 2nd, one treatment starting at a 2 inch depth and the other at a 3 inch depth. Thereafter, they also were undercut and lateral pruned every five weeks until October 24th. Two additional undercutting treatments were begun on June 16th, one starting at a 2 inch depth and the other at a three inch depth, and they also were retreated every five weeks until October 24th. After the initial undercutting, succeeding undercuts

Table 10. Average survival at age one and three and average height (in feet) at age three, by treatment and nursery.

	Sussex			New Kent		
	Survival		Height at	Survival		Height at
Treatment	Age 1	Age 3	Age 3	Age 1	Age 3	Age 3
1. June only	80.0	72.5	2.9	83.8	81.2	2.9
2. Oct. only	73.8	70.0	2.5	80.0	80.0	3.0
3. June, Aug., Oct., increasing	81.2	78.8	2.9	83.8	80.0	3.1
4. June, Aug., Oct., constant	81.2	81.2	2.8	86.2	81.2	2.8
5. June, July, Aug., Sept., Oct., increasing	76.2	71.2	2.7	86.2	83.8	2.8
6. June, July, Aug., Sept., Oct., constant	78.8	75.0	2.7	81.2	77.5	3.1
7. Control	43.8	42.5	2.5	76.2	73.8	2.9
Means	73.6	70.2	2.7	82.5	79.6	3.0

were done 1 inch deeper until a depth of 5 inches was reached, which remained the undercutting depth until the final cut. The treatments are listed below.

1. Control, not root pruned.
2. Undercut 7 times, starting on March 28th, at depths of 2, 3, 4, 5, 5, 5, and 5 inches.
3. Undercut 6 times, starting on May 2nd, at depths of 2, 3, 4, 5, 5, and 5 inches.
4. Undercut 6 times, starting on May 2nd, at depths of 3, 4, 5, 5, 5, and 5 inches.
5. Undercut 5 times, starting on June 16th, at depths of 2, 3, 4, 5, and 5 inches.
6. Undercut 5 times, starting on June 6th, at depths of 3, 4, 5, 5, and 5 inches.

The actual dates for undercutting and lateral pruning were:

March 28
May 2
June 6
July 11
August 14
September 19
October 25

This study was installed only at our Sussex Nursery. Undercutting and lateral pruning treatments were applied to entire seedbeds in three different seedbed sections, randomly assigning the treatments to beds three through eight.

Top clipping was added as a treatment, mowing a 40-foot-long plot at a height of 8 inches on July 11th in each root pruned and control seedbed. Half of each 40-foot plot was clipped again on September 19th, at a height of 8 to 9 inches. This increased the number of treatments to 18, six root pruning treatments times three top clipping treatments (unclipped, clipped once, and clipped twice).

We lifted seedling samples on February 14th and 20th. From each seedbed, we lifted three samples, each 6 inches wide for a 2-square-foot sample. We took samples from the center of each top clipped plot (clipped once or twice) and a sample of unclipped seedlings adjacent to the top clipped seedlings. This was done for the six beds of each of the three sections, for a total of 54 samples.

The seedlings were measured and selected for planting on February 27th and 28th. We measured the diameter and top length of each seedling and separated them by root collar diameter, keeping the seedlings from each of the three samples of each treatment separate until we could select seedlings for planting. We needed 80 seedlings from each treatment to plant, for four 20-seedling rows in the field. Seedlings were selected proportional to the number of seedlings in each diameter class. We discarded seedlings below 3.5/32nds and calculated the number of seedlings we would need from each diameter class, from each of the three samples in order to obtain the 80 seedlings we needed. To prevent the roots from drying out, while all of this measuring and counting was done, we misted the roots frequently with water and kept them covered with plastic. After putting together the 20-seedling bundles, we pruned the roots to about 6 inches and dipped them in clay.

The seedlings were planted on March 4th, in four randomized blocks, with a 20-seedling row of each of the 18 treatments in each block, for a total of 72 rows and 1,440 seedlings.

Root pruning improved survival an average of 13 percentage points (58.1 versus 45.0), comparing the average of the five root pruning treatments with the control (Table 11). Top clipping had no effect on survival (Table 12). In an analysis of variance of survival at age three, after first transforming to arc sine percent, the main effect of pruning was statistically significant (probability of a larger F = .007), while top clipping was not (probability of a larger F = .98). Orthogonal comparisons were made, and the only significant comparison was the average of the five root pruning treatments versus the control (probability of a larger F = .0008). The differences between 5 and 6 root prunings and starting

at a 2 or 3 inch depth (for 5 and 6 prunings) were not significant (probability of a larger F = .278 and .625 respectively).

Root pruning increased height at age three (Table 11) but the differences were not statistically significant. Of four orthogonal comparisons involving root pruning, the one closest to being significant was the average of the five root pruning treatments versus the control (probability of a larger F = .075). Top clipping, on the other hand, significantly reduced height at age three as shown in Table 12 (probability of a larger F = .000000008).

1990 Operational Root Pruning Study

There were three full sections of 2-0 white pine at Sussex that were not included in the main study. These were operationally root pruned twice, leaving one bed in each section as an unpruned control. Undercutting and lateral pruning were done twice, on March 29th and May 11th, both times at an undercutting depth of about 3 inches. At New Kent, five full sections of 2-0 white pine were operationally root pruned three times, leaving one bed in each section as an unpruned control. Undercutting was done three times, on April 12th and 13th, August 20th and 21st , and October 14th. The undercutting depth was 3 inches the first time and 4½ inches the second and third time. Lateral pruning was done each time undercutting was done.

Seedlings were lifted on February 12th at New Kent and February 14th at Sussex. We lifted 20 samples at each nursery, each sample 6 inches wide for a 2-square-foot sample. Samples were paired, so that a root pruned and control sample were taken side by side in adjacent seedbeds. At New Kent, we lifted two paired samples (4 samples in all) from each of the five sections. At Sussex, we lifted three paired samples from two of the sections and four paired samples from the third section.

The New Kent seedlings were measured on February 13th and the Sussex seedlings on February 15th. All seedlings from each sample were measured for root collar diameter and top length, and separated by root collar diameter. We selected 20 seedlings from each sample, proportional to the number of seedlings in each diameter class. This provided enough seedlings for 40 rows in the field, 20 from New Kent, and 20 from Sussex. The roots of the 20

Table 11. Average survival at ages 1, 2, and 3, and average height in feet at age 3, by root pruning treatment.

Root Pruning Treatment	Survival Percent			Average Height Age 3
	Age 1	Age 2	Age 3	
Control	49.2	45.4	45.0	2.1
7 cuts, 2 inches	71.7	65.4	63.8	2.4
6 cuts, 2 inches	69.2	61.7	59.6	2.2
6 cuts, 3 inches	63.2	57.8	57.3	2.2
5 cuts, 2 inches	64.2	56.7	55.4	2.3
5 cuts, 3 inches	59.6	54.6	54.6	2.4
Means	62.8	56.9	55.9	2.3

Table 12. Average survival at ages one, two, and three, and average height in feet at age three, by top clipping treatment.

Number of Clippings	Survival Percent			Average Height Age 3
	Age 1	Age 2	Age 3	
0	61.8	57.4	56.0	2.6
1	61.7	56.0	55.6	2.2
2	65.0	57.1	56.2	2.0
Means	62.8	56.8	55.9	2.3

seedling bundles were pruned to about 6 inches and dipped in clay.

The seedlings were planted on the Appomattox-Buckingham State Forest on February 19th in 10 randomized blocks of 4 rows each. The four rows in a block contained a paired sample (root pruned and not root pruned) from each nursery. This provided a total of 40 rows and 800 seedlings.

Root pruning improved survival at both nurseries, but had no effect on height (Table 13). Sussex seedlings survived better than New Kent seedlings. In an analysis of variance for survival at age three, after transforming to arc sine percent, the improvement from pruning was significant and the difference between nurseries was not (probability of a larger F = .0002 and .210 respectively).

1991 Study

We root pruned just three times, starting on different dates and at different depths for a total of seven treatments. Root pruning treatments were applied to entire beds in two sections at Sussex and one section at New Kent. The treatments are listed separately by nursery below.

Sussex Nursery

1. Undercut on Apr. 29th, July 16th, and Oct. 2nd, at 2, 4½, and 4½ inch depths.
2. Undercut on Apr. 29th, July 16th, and Oct. 2nd, at 4, 4½, and 4½ inch depths.
3. Undercut on May 24th, July 16th, and Oct. 2nd, at 2, 4½, and 4½ inch depths.
4. Undercut on May 24th, July 16th, and Oct. 2nd, at 4, 4½, and 4½ inch depths.
5. Undercut on June 19th, Aug. 9th, and Oct. 2nd, at 3, 4½, and 4½ inch depths.
6. Undercut on June 19th, Aug. 9th, and Oct. 2nd, at 4, 4½, and 4½ inch depths.
7. Unpruned control.

New Kent Nursery

1. Undercut on Apr. 11th, July 11th, and Sept. 11th, at 2, 4½, and 4½ inch depths.
2. Undercut on Apr. 11th, July 11th, and Sept. 11th, at 4½, 4½, and 4½ inch depths.
3. Undercut on May 9th at 2 inch depth, and then abandoned.
4. Undercut on May 9th at 4½ inch depth, and then abandoned.
5. Undercut on June 11th, Aug. 11th, and Oct. 11th, at 3, 4½, and 4½ inch depths.
6. Undercut on June 11th, Aug. 11th, and Oct. 11th, at 4½, 4½, and 4½ inch depths.
7. Unpruned control.

Treatments three and four at New Kent were abandoned because of insufficient irrigation following pruning, and severe wilting and some mortality occurred.

Lateral pruning was done every time that undercutting was done at both nurseries.

Seedling samples were lifted at Sussex on January 2nd. Samples were 6 inches wide across the seedbed for a 2-square-foot sample. We lifted a single sample from each seedbed initially, and realized that we wouldn't have

Table 13. Average survival at age one, two, and three and average height in feet at age three.

	Sussex				New Kent			
	Survival			Height	Survival			Height
	Age 1	Age 2	Age 3	Age 3	Age 1	Age 2	Age 3	Age 3
Control	52.5	49.5	48.5	2.8	51.0	47.0	46.5	3.0
Root pruned	70.0	67.5	66.5	2.7	64.5	60.0	59.5	3.0
Difference	17.5	18.0	18.0	.1	13.5	13.0	13.0	0.0

enough seedlings for the field planting. We then lifted another set of samples from one of the two sections, flipping a coin to decide which section to take the second set from. We needed 100 seedlings, enough for five replications in the field, from each of the seven treatments. On January 17th, we measured the root collar diameter and top length of every seedling in each sample, and separated by root collar diameter. From the three samples from each treatment, we selected seedlings proportional to the number of seedlings in each diameter class and each sample to obtain the 100 seedlings we needed to plant in the field. We were careful to keep the roots damp while we did all of this measuring and counting. The seedlings were planted on January 22nd, on the Appomattox-Buckingham State Forest.

We lifted the New Kent seedlings on January 29th. We lifted three samples from each seedbed, each 6 inches wide across the seedbed for a 2-square-foot sample. This gave us a total of 15 samples (two of the treatments had been abandoned, so there were only five treatments left). We measured the seedlings and made up the seedling packages the same day, following the same procedure as for the Sussex seedlings. The seedlings were planted on February 5th.

Both the Sussex and New Kent seedlings were planted in the same randomized blocks. There were five blocks, each containing 12 rows of 20 seedlings each, a row each of the seven Sussex treatments and five New Kent treatments.

After two seasons in the field, combining root pruning treatments, root pruning increased survival by 15.7 points (74.7 versus 59.0) at Sussex and 22.2 points (72.2 versus 50.0) at New Kent. Sussex seedlings survived slightly better than New Kent seedlings (Table 14). An analysis of variance of survival at age two, after first transforming to arc sine percent, was performed including orthogonal comparisons. The only significant comparison was the average of all root pruning treatments versus the control (probability of a larger F = .00034).

DISCUSSION

Loblolly seedlings have benefitted only slightly from undercutting. This is hard to explain because seedlings dramatically changed root morphology in ways that might be expected to improve field performance. Multiple undercutting (and lateral pruning) produced more compact root systems with many more fine roots and at least twice as many mycorrhizae (although mycorrhizae were never counted or quantified).

Overall survival improvement from root pruning loblolly seedlings, combining pruning treatments and comparing to unpruned control seedlings, was only 2, 1, 2, 2, 0, and -1 percentage points for six studies (excluding the pilot study beginning when seedlings were only 2 or 3 inches tall). Consequently, we do not root prune loblolly seedlings in the seedbed.

Survival of unpruned control seedlings was very good in all of these studies, leaving little room for improvement by root pruning. Unpruned seedling survival was 88, 91, 96, 96, 94, 94, and 97 percent in the seven studies. Had survival been lower, perhaps the improve-

Table 14. Average survival at age one and two.

	Sussex		New Kent	
Treatment	Age 1	Age 2	Age 1	Age 2
1. Start in April, 2 inches	88	77	86	73
2. Start in April, 4 or 4½ inches	85	78	82	71
3. Start in May, 2 inches	79	71	--	--
4. Start in May, 4 inches	85	74	--	--
5. Start in June, 3 inches	85	76	79	68
6. Start in June, 4 or 4½ inches	82	72	81	77
7. Control	63	59	57	50

ment from root pruning would have been greater.

One advantage of root pruning is that it controls (reduces) height growth in the seedbed. However, root pruning reduces growth of all seedlings, large and small. We control height growth of loblolly seedlings by top clipping. It reduces growth only for the taller seedlings that are actually clipped. Also, top-clipping is a much easier, faster, and cheaper operation than root pruning.

We tried to prevent wilting by irrigating before and after root pruning, but some nurserymen purposely let root-pruned seedlings wilt before irrigating to impose moisture stress.

All of these studies were hand-lifted using reasonable care, but hand-lifting probably does more root damage than careful lifting with a full-bed mechanical lifter. Root pruning makes it easier to hand-lift seedlings. Consequently, we probably caused more root damage to unpruned control seedlings than root pruned seedlings. We hope this was a minor factor, but its effect, if and where it occurred, was probably to favor root pruned over unpruned seedlings.

Root-pruned seedlings are harder to plant with a traditional planting bar, and the more times seedlings are pruned, the harder they are to plant. With loblolly, frequent pruning produces a soft, brush-like root system without a single, stiff taproot. The roots hang up on the sides of the planting hole, increasing the amount of folding and making deep planting more difficult. With white pine, frequent pruning produces a rectangular root system, as viewed from above, with short, rigid, spreading, lateral roots that are hard to stuff in a planting slit. The easiest seedlings to plant with a planting bar are medium-sized, unpruned seedlings with a single, stiff, straight, tap root that has been cut to a 5 or 6 inch length by the lifting machine.

Survival improvement from root pruning white pine, on the other hand, was substantial in all five studies. Combining root pruning treatments and comparing to unpruned control seedlings for the five studies, the improvement was 20, 20, 13, 16, and 19 percentage points (this also combined New Kent and Sussex seedlings). Consequently, root pruning white pine is operational at our New Kent and Sussex nurseries. We never have operationally top clipped white pine seedlings, and the 1990 study suggests that top clipping is of no benefit to white pine.

As the season progresses, it becomes more and more difficult to see the individual drill rows in white pine seedbeds, and thus keep the lateral pruner blades between the rows. We are inclined to omit lateral pruning when the final undercutting is done.