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Root Pruning White Pine Seedlings in the Seedbed

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Abstract

Five separate undercutting studies that involved varying the frequency, timing, and depth of undercutting were installed in 1988, 89, 90, and 91. Lateral root pruning was done each time undercutting was done. The studies were installed at our New Kent and Sussex nurseries.

Root pruning resulted in substantial gains in survival in all five studies. Combining the various root pruning treatments each year, the average gains over the unpruned control seedlings ranged from 13 to 20 percentage points, and averaged 18 points. None of the differences related to frequency of pruning, timing of pruning, or depth of pruning were statistically significant in any of the five studies. Height growth in the field was improved slightly by root pruning, an average of about 0.1 feet after 3 years in the field.

Introduction

Studies were installed in 1988, 1989, 1990, and 1991 that involved both undercutting and lateral root pruning. Identical studies were installed each year at both our New Kent and Sussex nurseries. The soils at both nurseries are deep and sandy, containing 90% or more sand in the top soil.

1988 STUDY

Procedure

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 2 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 3 weeks and the other about every 4 weeks, starting in early June. We made a total of 6 prunings for the plots root pruned about every 3 weeks and 5 prunings for those pruned about every 4 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 12 at New Kent and February 22 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 $^{1}/_{32}$-inch diameter classes. The New Kent seedlings were measured on February 2 and the Sussex seedlings on February 27. Seedlings for planting in the field were selected proportional to the number of seedlings in each diameter class, discarding all seedlings less than $^{3}/_{32}$-inch diameter. Forty seedlings were selected from each sample, enough for 2 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 2 on the Appomattox-Buckingham State Forest and on April 6 in Botetourt County.

Seedbed Results

Root pruning decreased average root collar diameter at New Kent, but had little effect at Sussex (Table 1).

Table 1. Average root collar diameter when lifted (in 32^{nds} inch).

Treatment	New Kent	Sussex
3 weeks, pruned	6.09	5.05
3 weeks, control	6.36	4.80
4 weeks, pruned	5.58	4.88
4 weeks, control	5.93	4.98

Field Results

Root pruning increased survival by about 20 percentage points. Three- and four-week pruning frequencies gave similar results (Table 2). Analyses of variance were performed on average survival at age 3, after transforming to arc sine percent. Separate analyses were performed for the Appomattox-Buckingham State Forest and Botetourt

County installations. Root pruning improved survival significantly at both locations (probability of a larger F = 0.004 and 0.002 at Buckingham and Botetourt respectively). Seedlings pruned every 4 weeks rather than every 3 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 3 at Buckingham (probability of a larger F = 0.006), but had no effect in Botetourt (Table 2).

Table 2. Average survival at age 1 and 3 and average height (in feet) at age 3.

	Appomattox-Buckingham State Forest			Botetourt County		
	Survival		Height	Survival		Height
Treatment	Age 1	Age 3	Age 3	Age 1	Age 3	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

1989 Study

Procedure

Seedlings were undercut once, 3 times, or 5 times. For the 3 and 5 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 3 times, in June, August, and October, at 5-inch depth
4. Undercut 3 times, in June, August, and October, at 3-, 4-, and 5-inch depths
5. Undercut 5 times, in June, July, August, September, and October, at 5-inch depth
6. Undercut 5 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 randomly applied to entire seedbeds using a Summit undercutter. The 7 interior beds of two 9-bed sections, 1 at Sussex and 1 at New Kent, provided 2 replications of the 7 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 3 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 15 and at New Kent on January 18. We lifted 3 samples from each seedbed, each sample 6 inches wide for a 2-square-foot sample. These samples were lifted from the center of the 3 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 17 and 18 and the New Kent seedlings on January 24 and 25. Seedlings below $^{4.5}/_{32}$ inch were discarded, and proportional numbers of seedlings from each diameter class of the 3 samples from each seedbed were selected for four 20-seedling rows in the field. This was done separately for each of the 7 treatments of each of the 2 seedbed replications.

Extra seedlings not planted in the field were saved and weighed on February 6. Seedlings less than $^{4.5}/_{32}$ inch had already been discarded. Roots were washed thoroughly and pruned by smoothing lateral roots down along the tap root and pruning 6 inches below the point where the first lateral emerged. Each seedling was then severed at the root collar and roots and tops were weighed. The number of seedlings weighed ranged from 31 to 67 for each pruning treatment from each nursery.

The seedlings were planted on January 26 on the Appomattox-Buckingham State Forest. We installed 4 randomized blocks, with a 20-seedling row of each of the 7 treatments from each nursery planted in each block, for a total of 56 rows and 1,120 seedlings.

We lifted some additional samples from the beds that had been undercut 3 and 5

times at increasing depths. These seedlings had not been laterally pruned, and samples were lifted adjacent to the 3 small, lateral pruning plots in each seedbed. These were measured and selected for planting in the same manner as for the main study, and were planted at the same time in the same randomized blocks. We considered this to be a small pilot study to see how much, if any, lateral pruning might add to the effect of undercutting.

Seedbed Results

Root pruning reduced root collar diameter and top length (Table 3). The effect of root pruning on seedling morphology seems to show up better in the weights of tops and roots (Table 4). At Sussex, the reduction in average top weight was related to the severity of pruning, with the greatest reduction for the 5-cut treatments and the least for the single cut in October. At New Kent, there was a similar but less clear-cut trend. "Recovered root" weight (roots less than 6 inches long) did not show a clear trend with frequency of cutting, but pruned root systems were heavier in most cases and shoot-to-root ratios were more favorable (Table 4).

Table 3. Average root collar diameter (32^{nds} inch) and top length (inches) by treatment and nursery.

	Sussex		New Kent	
Treatment	**Diameter**	**Length**	**Diameter**	**Length**
1. 6 only	6.2	10.8	6.2	11.3
2. 10 only	6.3	11.3	6.7	10.9
3. 6, 8, 10 increasing	6.7	10.9	6.4	10.9
4. 6, 8, 10, constant	6.3	10.3	6.1	10.3
5. 6, 7, 8, 9, 10 increasing	6.3	9.8	6.2	9.4
6. 6, 7, 8, 9, 10 constant	6.2	9.9	5.9	10.0
7. Control	6.8	11.7	6.3	11.0

Table 4. Average top and root weights (in grams) and top-to-root ratios by treatment and nursery.

	Sussex			New Kent		
Treatment	**Top**	**Root**	**Ratio**	**Top**	**Root**	**Ratio**
1. 6 only	11.6	3.4	3.4	13.1	3.9	3.4
2. 10 only	14.6	3.0	4.9	17.1	4.6	3.7
3. 6, 8, 10 increasing	12.8	4.3	3.0	15.1	6.0	2.5
4. 6, 8, 10, constant	12.4	4.0	3.1	12.5	5.0	2.5
5. 6, 7, 8, 9, 10 increasing	11.4	4.1	2.8	12.7	5.3	2.4
6. 6, 7, 8, 9, 10 constant	11.4	3.1	3.7	12.6	5.1	2.5
7. Control	17.2	3.1	5.5	14.7	3.4	4.3

Field Results

The New Kent seedlings survived and grew better than the Sussex seedlings (Table 5). Root pruning, combining the 6 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 = 0.004 and 0.002 respectively). Orthogonal comparisons were made, and the only significant comparison was between the average of all 6 pruning treatments and the control (probability of a larger F = 0.00004). 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 6 pruning treatments and the control, the probability of a larger F = 0.21).

Table 5. Average survival at age 1 and 3 and average height (in feet) at age 3, by treatment and nursery.

	Sussex			New Kent		
	Survival		Height	Survival		Height
Treatment	Age 1	Age 3	Age 3	Age 1	Age 3	Age 3
1. 6 only	80.0	72.5	2.9	83.8	81.2	2.9
2. 10 only	73.8	70.0	2.5	80.0	80.0	3.0
3. 6, 8, 10, increasing	81.2	78.8	2.9	83.8	80.0	3.1
4. 6, 8, 10, constant	81.2	81.2	2.8	86.2	81.2	2.8
5. 6, 7, 8, 9, 10, increasing	76.2	71.2	2.7	86.2	83.8	2.8
6. 6, 7, 8, 9, 10, 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**

Height growth was improved by root pruning the Sussex seedlings, but not the New Kent seedlings (Table 5). In an analysis of variance, the height difference at age 3 between the Sussex and New Kent seedlings was statistically significant (probability of a larger F = 0.00005).

The seedlings that had not been laterally pruned did not survive quite as well. Lateral pruning, for seedlings undercut 3 or 5 times at an increasing depth, survived 2.5 percentage points better for each nursery (75.5 versus 72.5 for Sussex and 81.9 versus 79.4 for New Kent).

1990 Main Study

Procedure

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 28, at an undercutting depth of 2 inches. Thereafter, undercutting was done every 5 weeks, ending on October 24, for a total of 7 cuts. Lateral pruning was done immediately after each undercutting, using a recently purchased Summit lateral pruner. As last year, we used the Summit undercutter. Two additional undercutting treatments were started on May 2, 1 treatment starting at a 2-inch depth and the other at a 3-inch depth. Thereafter, they also were undercut and lateral pruned every 5 weeks until October 24. Two additional undercutting treatments were begun on June 16, 1 starting at a 2-inch depth and the other at a 3-inch depth, and they also were retreated every 5 weeks until October 25. After the initial undercutting, succeeding undercuts 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 28, at depths of 2, 3, 4, 5, 5, 5, and 5 inches.
3. Undercut 6 times, starting on May 2, at depths of 2, 3, 4, 5, 5, and 5 inches.
4. Undercut 6 times, starting on May 2, at depths of 3, 4, 5, 5, 5, and 5 inches.
5. Undercut 5 times, starting on June 16, at depths of 2, 3, 4, 5, and 5 inches.
6. Undercut 5 times, starting on June 6, 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 3 different seedbed sections, randomly assigning the treatments to beds 3 through 8.

Top clipping was added as a treatment, mowing a 40-foot-long plot at a height of 8 inches on July 11 in each root pruned and control seedbed. Half of each 40-foot plot was clipped again on September 19, at a height of 8 to 9 inches. This increased the number of treatments to 18, 6 root pruning treatments times 3 top clipping treatments (unclipped, clipped once, and clipped twice).

We lifted seedling samples on February 14 and 20. From each seedbed, we lifted 3 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 6 beds of each of the three sections, for a total of 54 samples.

The seedlings were measured and selected for planting on February 27 and 28. We measured the diameter and top length of each seedling and separated them by root collar diameter, keeping the seedlings from each of the 3 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 3.5/32 and calculated the number of seedlings we would need from each diameter class, from each of the 3 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 4, in 4 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.

Seedbed Results

Root pruning and top clipping reduced root collar diameter and top length (Table 6 and 7). As would be expected, top clipping reduced top length more than root pruning. Average seedbed density for the 18 treatments ranged from 17.2 to 27.2 per square foot and averaged 21.1.

Table 6. Average root collar diameter (32nds inch) by treatment.

	Number of Clippings			
Root Pruning	**0**	**1**	**2**	**Means**
Control	7.3	6.2	6.7	6.7
7 cuts, 2 inches	6.3	6.0	6.0	6.1
6 cuts, 2 inches	6.6	6.0	6.4	6.3
6 cuts, 3 inches	7.0	5.8	6.2	6.4
5 cuts, 2 inches	6.6	6.5	6.1	6.4
5 cuts, 3 inches	6.9	6.5	6.7	6.7
Means	**6.8**	**6.2**	**6.4**	**6.4**

Table 7. Average top length (inches) by treatment.

	Number of Clippings			
Root Pruning	**0**	**1**	**2**	**Means**
Control	11.4	9.8	9.0	10.1
7 cuts, 2 inches	10.0	9.0	9.0	9.3
6 cuts, 2 inches	10.6	9.1	8.7	9.5
6 cuts, 3 inches	10.4	8.9	8.7	9.3
5 cuts, 2 inches	10.4	8.8	8.6	9.3
5 cuts, 3 inches	11.0	9.0	8.9	9.6
Means	**10.7**	**9.1**	**8.8**	**9.5**

Field Results

Root pruning improved survival an average of 13 percentage points (58.1 versus 45.0), comparing the average of the 5 root pruning treatments with the control (Table 8). Top clipping had no effect on survival (Table 9). In an analysis of variance of survival at age 3, after first transforming to arc sine percent, the main effect of pruning was statistically significant (probability of a larger F = 0.007), while top clipping was not (probability of a larger F = 0.98). Orthogonal comparisons were made, and the only significant comparison was the average of the 5 root pruning treatments versus the

control (probability of a larger F = 0.0008). 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 = 0.278 and 0.625 respectively).

Table 8. Average survival at ages 1, 2, and 3, and average height in feet at age 3, by root pruning treatment.

	Survival Percent			Average Height
Root Pruning Treatment	Age 1	Age 2	Age 3	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 9. Average survival at ages 1, 2, and 3, and average height in feet at age 3, by top clipping treatment.

	Survival Percent			Average Height
Number of Clippings	Age 1	Age 2	Age 3	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**

Root pruning increased height at age 3 (Table 8) but the differences were not statistically significant. Of 4 orthogonal comparisons involving root pruning, the 1 closest to being significant was the average of the 5 root pruning treatments versus the control (probability of a larger F = 0.075). Top clipping, on the other hand, significantly reduced height at age 3 as shown in Table 9 (probability of a larger F = 0.000000008).

1990 Operational Root Pruning Study

Procedure

There were 3 full sections of 2-0 white pine at Sussex that were not included in the main study. These were operationally root pruned, leaving 1 bed in each section as an unpruned control. Undercutting and lateral pruning were done twice, on March 29 and May 11, both times at an undercutting depth of about 3 inches.

At New Kent, 5 full sections of 2-0 white pine were operationally root pruned, leaving 1 bed in each section as an unpruned control. Undercutting was done 3 times, on April 12 and 13, August 20 and 21, and October 14. The undercutting depth was 3 inches the first time and about 4½ inches the second and third time. Lateral pruning was done each time undercutting was done.

At both nurseries, seedlings were watered before and after undercutting.

Seedlings were lifted on February 12 at New Kent and February 14 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 2 paired samples (4 samples in all) from each of the five sections. At Sussex, we lifted 3 paired samples from 2 of the sections and 4 paired samples from the third section.

The New Kent seedlings were measured on February 13 and the Sussex seedlings on February 15. 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 seedling bundles were pruned to about 6 inches and dipped in clay.

The seedlings were planted on the Appomattox-Buckingham State Forest on February 19 in 10 randomized blocks of 4 rows each. The 4 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.

Seedbed Results

Root pruning reduced root collar diameter and top length at both nurseries (Table 10). Average seedbed density at New Kent was 31.3 and 29.1 seedlings per square foot for undercut and control seedlings respectively. At Sussex, average seedbed density was 24.2 and 22.2 seedlings per square foot for undercut and control seedlings respectively.

Table 10. Average root collar diameter (32nds inch) and top length (inches).

	Sussex		New Kent	
	Diameter	Length	Diameter	Length
Pruned	5.97	10.3	5.91	10.7
Control	6.17	10.6	6.31	11.7
Difference	**.20**	**0.3**	**0.40**	**1.0**

Field Results

Root pruning improved survival at both nurseries, but had no effect on height (Table 11). Sussex seedlings survived better than New Kent seedlings. In an analysis of variance for survival at age 3, after transforming to arc sine percent, the improvement from pruning was significant and the difference between nurseries was not (probability of a larger F = 0.0002 and 0.210 respectively).

Table 11. Average survival at age 1, 2, and 3 and average height in feet at age 3.

	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**

1991 Study

We root pruned just 3 times, starting on different dates and at different depths for a total of 7 treatments. Root pruning treatments were applied to entire beds in 2 sections at Sussex and 1 section at New Kent. The treatments are listed separately by nursery below.

Sussex Nursery

1. Undercut on April 29, July 16, and October 2, at 2, 4½, and 4½ inch depths.
2. Undercut on April 29, July 16, and October 2, at 4, 4½, and 4½ inch depths.
3. Undercut on May 24, July 16, and October 2, at 2, 4½, and 4½ inch depths.
4. Undercut on May 24, July 16, and October 2, at 4, 4½, and 4½ inch depths.
5. Undercut on June 19, August 9, and October 2, at 3, 4½, and 4½ inch depths.
6. Undercut on June 19, August 9, and October 2, at 4, 4½, and 4½ inch depths.
7. Unpruned control.

New Kent Nursery

1. Undercut on April 11, July 11, and September 11, at 2, 4½, and 4½ inch depths.
2. Undercut on April 11, July 11, and September 11, at 4½, 4½, and 4½ inch depths.
3. Undercut on May 9 at 2 inch depth, and then abandoned.
4. Undercut on May 9 at 4½ inch depth, and then abandoned.
5. Undercut on June 11, August 11, and October 11, at 3, 4½, and 4½ inch depths.
6. Undercut on June 11, August 11, and October 11, at 4½, 4½, and 4½ inch depths.
7. Unpruned control.

Treatments 3 and 4 at New Kent were abandoned because of insufficient irrigation following pruning. 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 2. 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 enough seedlings for the field planting. We then lifted another set of samples from 1 of the 2 sections, flipping a coin to decide which section to take the second set from. We needed 100 seedlings, enough for 5 replications in the field, from each of the 7 treatments. On January 17, we measured the root collar diameter and top length of every seedling in each sample, and separated by root collar diameter. From the 3 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 22, on the Appomattox-Buckingham State Forest.

We lifted the New Kent seedlings on January 29. We lifted 3 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 (2 of the treatments had been abandoned, so there were only 5 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 5.

Both the Sussex and New Kent seedlings were planted in the same randomized blocks. There were 5 blocks, each containing 12 rows of 20 seedlings each, a row each of the seven Sussex treatments and 5 New Kent treatments. Sussex seedlings were planted on January 22 and New Kent on February 5.

Seedbed Results

Root collar diameter and top length were reduced for the root pruning treatments starting in April and May, but not in June (Table 12). Average seedbed densities ranged from 20.3 to 24.2 seedlings per square foot for the 7 Sussex treatments, and 23.8 to 26.2 for the 5 New Kent treatments.

Table 12. Average root collar diameter in 32^{nds} inch and top length in inches.

	Sussex		New Kent	
Treatment	**Diameter**	**Length**	**Diameter**	**Length**
1. Start April, 2 inches	5.38	8.9	5.56	9.9
2. Start April, 4 or 4½ inches	5.94	9.0	6.05	10.6
3. Start May, 2 inches	5.65	8.7	--	--
4. Start May, 4 inches	6.00	9.0	--	--
5. Start June, 3 inches	6.31	11.6	6.18	12.7
6. Start June, 4 or 4½ inches	6.53	10.3	6.14	11.5
7. Control	6.37	10.6	6.19	12.3

Field Results

Combining root pruning treatments, root pruning increased survival by 14.2 points (73.2 versus 59.0) at Sussex and 21.0 points (71.0 versus 50.0) at New Kent. Sussex seedlings survived slightly better than New Kent seedlings (Table 13). In an analysis of variance of survival at age 3 (after first transforming to arc sine percent), the May treatments at the Sussex nursery, were excluded so that orthogonal comparisons could be made. The only statistically significant comparison was between the average of all pruning treatments and the controls for both nurseries combined (probability of a larger F = 0.00026). Varying the pruning depth or starting in April rather than June did not significantly affect survival, and the difference in average survival between Sussex and New Kent was not significant.

Table 13. Average survival at age 1, 2, and 3, and average height (in feet) at age 3.

	Sussex				New Kent			
	Survival			Height	Survival			Height
Treatment	Age 1	Age 2	Age 3	Age 3	Age 1	Age 2	Age 3	Age 3
1. Start in April, 2 inches	88	77	75	2.6	86	73	72	2.9
2. Start in April, 4 or 4½ inches	85	78	78	2.8	82	71	68	3.0
3. Start in May, 2 inches	79	71	71	2.9	--	--	--	--
4. Start in May, 4 inches	85	74	71	2.6	--	--	--	--
5. Start in June, 3 inches	85	76	74	2.9	79	68	67	3.2
6. Start in June, 4 or 4½ inches	82	72	70	2.9	81	77	77	2.9
7. Control	63	59	59	2.7	57	50	50	2.6

Height growth was increased by root pruning (Table 13). Combining root pruning treatments, root pruning increased average height at age 3 by 0.1 foot for Sussex seedlings and 0.4 foot for New Kent seedlings. In an analysis of variance of height at age 3, the May treatments at Sussex were again excluded and orthogonal comparisons were made. The following comparisons were statistically significant.

Comparison	Average Difference (feet)	Probability of a Larger F
1) Sussex vs. New Kent	0.12	0.025
2) Pruned vs. Control	0.27	0.00011
3) Interaction of nursery with pruning	--	0.015
4) April vs. June	0.14	0.015
5) Interaction of month with depth of undercutting	--	0.037

Discussion

Root pruning improved survival considerably in all five studies. The overall, average improvement, combining root pruning treatments, was 20, 20, 13, 16, and 19 percentage points in 1988, 1989, 1990 (two studies), and 1991 respectively. Compared to loblolly[1], the survival of unpruned control seedlings was low (58, 58, 45, 48, and 59 percentage points), so that there was "plenty of room" for improvement from root pruning.

Root pruning improved height growth slightly for four of the five studies during the first 3 years in the field. The overall average improvement, combining root pruning treatments, was 0.24, 0.15, 0.15, -0.05, and 0.27 feet at age 3 in 1988, 1989, 1990 (two studies), and 1991 respectively.

Unlike loblolly[1], root pruning had little effect on root morphology. Pruned root systems were more compact, of course, but numbers of fine roots and mycorrhizae were not greatly increased, as occurred when loblolly was root pruned in these same nursery soils.

Survival differences related to frequency, timing, and depth of undercutting were not statistically significant in any of the studies, although there seem to be some trends. We think that 3 undercuttings are probably sufficient, that the first 1 ought to be done early, soon after the seedlings start to grow in the spring, and that a constant depth of 4½ or 5 inches for all 3 undercuttings is as good (and easier) than increasing the depth throughout the season.

[1]See Occasional Report #115, Additional Tests of Root Pruning Loblolly Pine Seedlings in the Seedbed.