Survival and Growth for the First-growing Season of Northern Red Oak (*Quercus rubra* L.) Seedlings Underplanted in Mixed Upland Hardwood Stands in South Central Iowa[1]

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Abstract: This paper reports the first year survival and growth of red oak seedlings underplanted in two mixed upland hardwood stands in south central Iowa. The underplanted seedlings were undercut and not undercut 1-0 red oak stock.

Fifteen blocks were laid out in 1990, with seven of the blocks receiving a foliar application of glyphosate herbicide. In the winter of 1990-1991, all non-oak trees were removed and their stumps treated with Picloram.

Treatment areas were established in the spring (1991). The trials encompassed ten seedlings from each of three root classes: 0-4, 5-9, and ten or more permanent, first-order, lateral roots greater than 1 mm. The seedlings were planted in randomly assigned rows. Tree shelters were randomly assigned to the first five or second five seedlings in each row.

The first growing season data show that spraying, tree shelters, and the number of lateral roots seem to be important in the establishment of red oak seedlings. Spraying was significant at reducing competition by 42%. Seedlings planted in tree shelters outperformed seedlings without tree shelters in average height growth (128%) and survival (7%). Seedlings with ten or more lateral roots had better average height growth than did seedlings with 0-4 (369%) and 5-9 (70%) lateral roots. The first growing season had 78% survival or better for all seedlings.

INTRODUCTION

A recent concern in the management of northern red oak (*Quercus rubra* L.) is the difficulty in regenerating new stands to replace those harvested (Holt and Fisher 1979, Johnson *et al.* 1984, Crow 1988, Lorimer 1989). The difficulty in regenerating red oak stands is that many oak forests in parts of Eastern and Central United States have developed dense understories of shade-tolerant species (Schlesinger 1976, Ehrenfeld 1980, Coder 1985). Thus, as red oak stands are harvested, they gradually convert to sugar maple (*Acer saccharum* Marsh.), American basswood (*Tilia*

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americana L.), American elm (*Ulmus americana* L.), and white ash (*Fraxinus americana* L.) because there is little or no advanced red oak reproduction (Sander 1977).

If no artificial regeneration is used, the percentage of red oak in the succeeding rotation is directly related to the amount of red oak reproduction present before final harvesting takes place. While stump sprouts can be anticipated, oak's ability to sprout decreases with age. Only 30% of northern red oak stumps are expected to sprout after they reach 43 cm in diameter (Sander 1977). Therefore, seedlings must be established to regenerate the new stand, because sprouts can not be depended on. This reproduction must be established over a period of time, either by natural or artificial regeneration before the mature overstory trees are harvested (Carvell 1979).

Sander *et al.* (1984) demonstrated in the Missouri Ozarks that red oak seedlings must be at least 1.5 m high or 2.5 cm in ground-line diameter to have the potential for reaching dominance in a new stand. It may take 10 to 20 years before an adequate amount of oak regeneration reaches these minimum sizes so that the overstory can be removed (Sander 1977). Such sluggish growth in red oak seedlings allows them to be overtopped by the competition at an early age and seems to be the primary reason for red oak regeneration failures (Johnson and Jacobs 1988, Kolb and Steiner 1989, Lorimer 1989).

Northern red oak seedlings have the capacity to grow rapidly because of their ability to have multiple flushes under optimal conditions. However, when stressed, as is typical in the field, red oak tends to have conservative shoot growth and allocates more photosynthate to root growth (Kolb and Steiner 1990). When red oak has a flush, it involves four distinct growth phases. The growth phases are lag phase (leaves fully expanded), bud phase (bud swell), stem linear phase (linear stem growth), and leaf linear phase (linear leaf growth). The lag phase is when root growth occurs (Dickson 1991).

Research, by Sander in the 1960's and 1970's developed the guidelines for establishing red oak regeneration. These guidelines state that 1,200 - 1,500 red oak seedlings/hectare at 1.5 m in height are needed to establish a pole stand containing 30% oak (Lorimer 1989). Obviously, very few stands located on average or good sites could even come close to Sander's guidelines for red oak regeneration (Lorimer 1989).

Current research is focused on finding ways to establish successfully red oak regeneration. Researchers are focused on: planting improved nursery stock, using tree shelters, herbicide control of competition, removal of understory and overstory vegetation, and combinations of these methods (Johnson 1976, Johnson 1981, Loftis 1985, Tuley 1985, Johnson *et al.* 1989, Potter 1991, Schultz and Thompson 1991, Teclaw and Isebrands 1991, Minter *et al.* 1992.)

STUDY OBJECTIVE

The objective of this study is to evaluate survival and growth of underplanted northern red oak seedlings in south central Iowa. This paper reports the results from the first year of the study.

STUDY AREA

The study is located in Lucas County in south central Iowa. The study was conducted in two upland, mixed, hardwood stands of 2.3 ha each. The stands are located on the McNay Research Farm and the Stephens State Forest.

Normal amount of annual precipitation in Lucas County is 88.42 cm. Annual precipitation for the establishment year, however, was 90.73 cm (NOAA 1991). Although the annual precipitation for the establishment year was 2.31 cm above normal, precipitation during the growing season, from June to September, was below normal (range from 3.76 cm to 8.05 cm below normal).

McNay Site

The McNay stand has a past history of grazing, which was abandoned approximately 15-20 years ago. Based on an initial inventory, the site index (base age = 50) was 20 m (s = 6) ("s" = standard deviation), with an average stocking level of 21.5 m^2/ha (s = 3). Based on findings of Gingrich (1971), the stand was 100% stocked. After cutting all non-oak trees greater than 2.54 cm in diameter at breast height (dbh), the average stocking level was reduced to 48% or 14.1 m^2/ha (s = 2.3).

Before cutting, the McNay stand had 1,565 trees/ha (s = 395) with an average dbh of 9.4 cm (Figure 1). The McNay site was regenerating to elm (*Ulmus* species) (1,726 seedlings /ha, s = 321), white oak (*Quercus alba* L.) (549 seedlings/ha, s = 124), ironwood (*Ostrya virginiana* (Mill.) K. Koch) (314 seedlings/ha, s = 74), and northern red oak, hackberry (*Celtis occidentalis* L.), and prickly ash (*Zanthoxylum americanum* Mill.) (235 seedlings/ha, s = 50). After all non-oak trees greater than 2.54 cm at dbh were cut, the stand had 95 trees/ha (s = 8.6), with an average dbh of 43.4 cm (Figure 1). Figure 2 presents a distribution of average basal area (m^2/ha) by 5 cm diameter classes for oak trees left on McNay and non-oak trees removed from McNay.

The soil types for McNay are gara and armstrong loams, which originated from glacial till parent material. Gara loam occupies 90% of the stand, and armstrong loam occupies 10% of the stand (Fenton 1992).

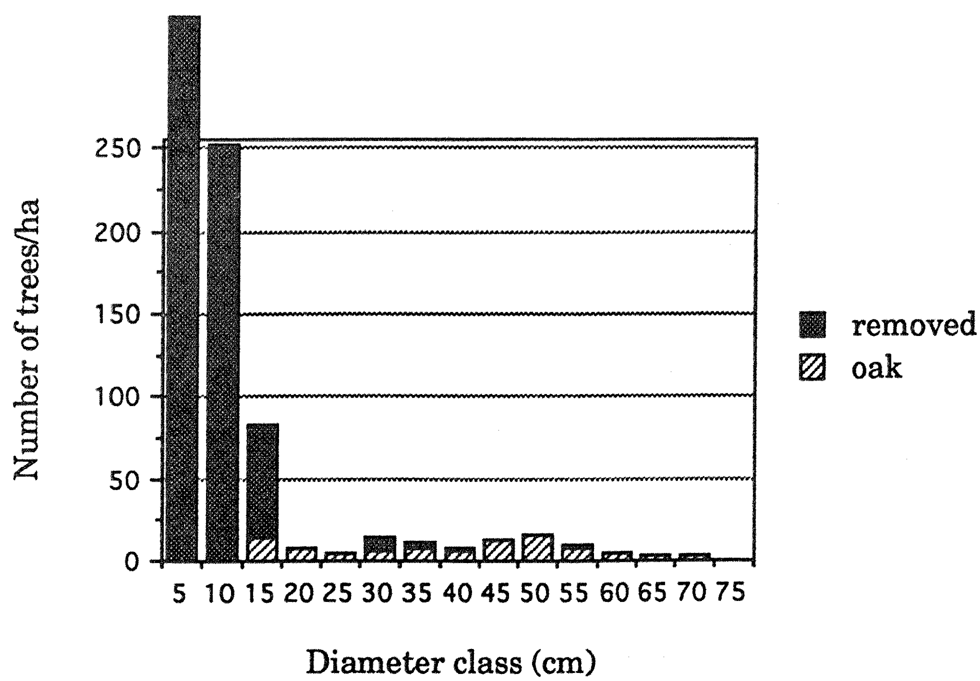

Figure 1.— Average number of trees/hectare by 5 cm diameter classes for oak trees left on McNay and non-oak trees removed from McNay.

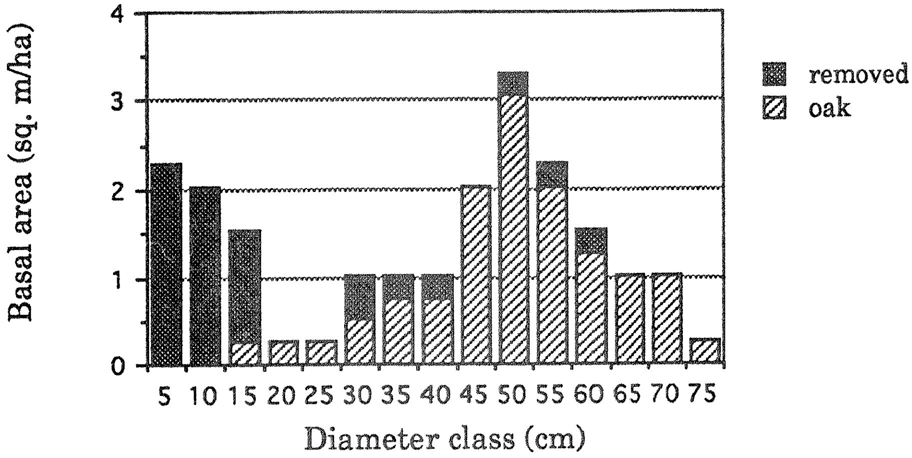

Figure 2.—Average basal area (m^2/ha) by 5 cm diameter classes for oak trees left on McNay and non-oak trees removed from McNay.

Stephens Site

Based on an initial tree inventory, the site index (base age = 50) for Stephens was 20 m (s = 6) with an average stocking level of 19.2 m^2/ha (s = 1.4). Based on Gingrich (1971), the stand was 75% stocked. After cutting all non-oak trees greater than 2.54 cm at dbh, the average stocking level was reduced to 60% or 15.9 sq. m./ha (s = 1.7).

Before cutting, the Stephens stand had 578 trees/ha (s = 118) with an average dbh of 18.7 cm (Figure 3). The stand was regenerating to dogwood (*Cornus* species) (2,236 seedlings/ha, s = 1,038), elm (1235 seedlings/ha, s = 244), white oak (882 seedlings/ha, s = 183), red oak (530 seedlings/ha, s = 183), hickory (*Carya* species), black cherry (*Prunus serotina* Ehrh.) (118 seedlings/ha, s = 37), and hackberry (59 seedlings/ha, s = 18.3) After cutting all non-oak trees greater than 2.54 cm dbh, the stand had 282 trees/ha (s = 43) with an average dbh of 26.7 cm (Figure 3). Figure 4 presents a distribution of average basal area (m^2/ha) by 5 cm diameter classes for oak trees left on Stephens and non-oak trees removed from Stephens.

The soil types for Stephens are welter silt, lindley, and keswick loams (Fenton 1992). The welter silt loam originated from loess parent material and occupies 55% of the stand. Lindley and keswick loams originated from glacial till parent material, and occupy 35% and 10% of the stand, respectively.

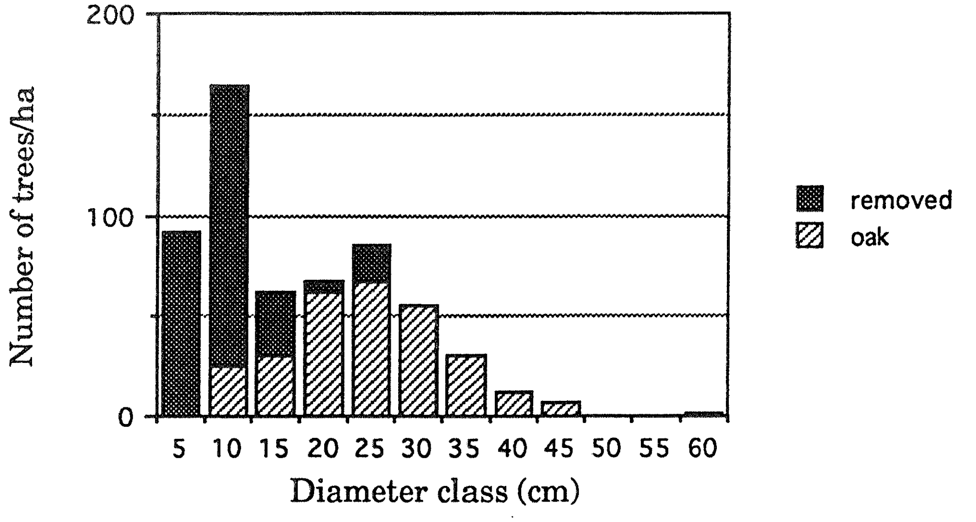

Figure 3.—Average number of trees/ha by 5 cm diameter classes for oak trees left on Stephens and non-oak trees removed from Stephens.

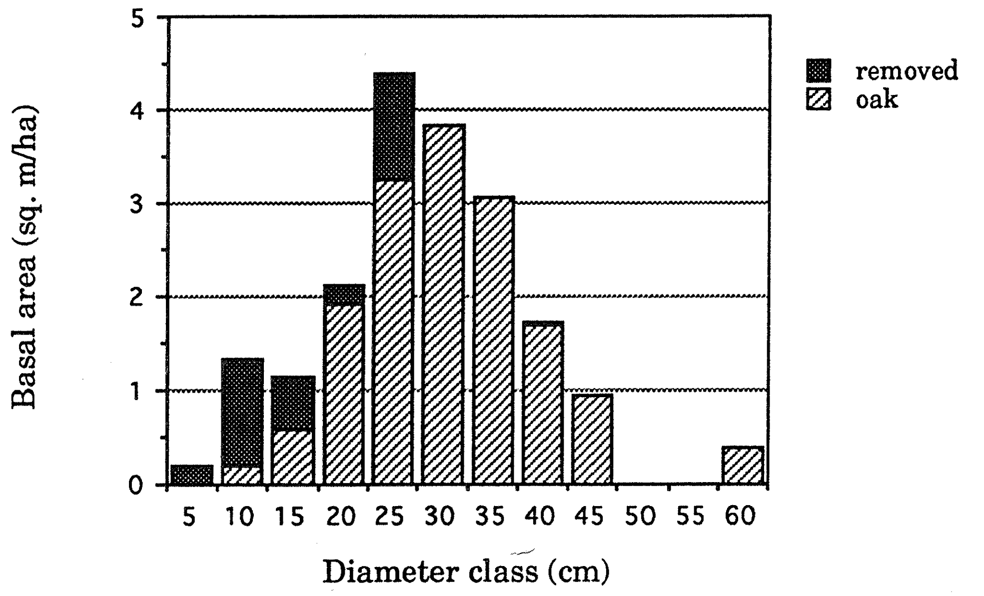

Figure 4.—Average basal area (m^2/ha) by 5 cm diameter classes for oak trees left on Stephens and non-oak trees removed from Stephens.

METHODS

Fifteen square blocks, 46 meters on each side, were laid out in August 1990 at McNay and Stephens (Figure 5). Glyphosate herbicide was applied in August 1990 to four randomly selected blocks on McNay and three randomly selected blocks on Stephens. A foliar application of glyphosate herbicide was applied to kill material less than 2.54 cm in diameter at 1.4 m above the ground. In the winter of 1990-91, all non-oak trees greater than 2.54 cm at 1.4 m above the ground were removed, and the stumps of those trees were treated with picloram.

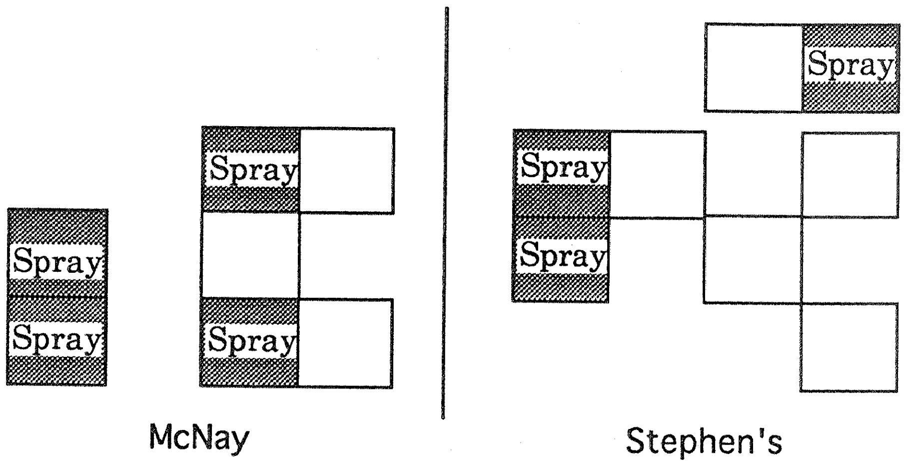

Figure 5.—Layout of blocks for each study area

After removal of non-oak trees, treatment areas were established during the spring of 1991. In each treatment area to be underplanted, 30 seedlings were planted in 3 rows of 10 seedlings per row at a spacing of 1.2 m between seedlings and 3 m between rows. Seedlings underplanted in half of the treatment areas had been undercut in the nursery, and the seedlings planted in the other half of the treatment areas had not been undercut.

Before underplanting, the undercut and not-undercut seedlings were graded by the number of permanent, first-order, lateral roots greater than 1 mm in basal diameter at the tap root. The seedlings were separated into the following root number classes: 0-4, 5-9, and 10 or more permanent, first-order, lateral roots greater than 1 mm. Permanent, first-order, lateral roots greater than 1 mm that originated from the callus wound area of undercut seedlings were also included in meeting the grading criteria.

As the seedlings were being graded, they were assigned a color coded numbered tag to keep track of each seedling. Initial height of each seedling was measured from the root collar to the tip of the terminal bud on the main leader, and initial caliper was measured just above the root collar.

Once the seedlings were underplanted, white tree shelters[3] that were four feet tall were randomly assigned to the first five seedlings or the second five seedlings in each row. White tree shelters were chosen, instead of the standard brown tree shelters, because of the lower level of light in the understory. Tree shelters were placed on the seedlings at the time of planting. The height and caliper at ground level of each seedling was recorded in the fall of 1991.

[3]The brand of tree shelters used was Tubex. Tubex was chosen based on its availability; this choice does not imply endorsement of this specific brand.

Competition was observed on mil-acre plots (0.0004 ha). A mil-acre plot was established at 3.8, 7.6, and 11.4 m along a transect in the middle of each treatment area. The mil-acre plots coincide with the middle planting row in each treatment. In each mil-acre plot the species, height, caliper at ground level of each stem less than 10 cm in diameter, and overstory basal area (live and dead) were recorded. The number of new competing seedlings was determined by the number of seedlings less than 4 mm in diameter at ground-line.

Data were collected on August 6-8, September 10-12, and September 24-26, 1991. The data covers first-growing season survival and height growth of northern red oak seedlings from planted 1-0 nursery stock seedlings and the competition with which the red oak seedlings had to contend. Because treatments had unequal sample sizes, statistical analyses were done using methods of least squares to fit general linear models (SAS Institute Inc. 1988). McNay and Stephens data were combined, because statistical analysis showed that location was not significant.

RESULTS

Underplanted Seedling Performance

Survival

The best seedling survival at the end of the first-growing season (1991) was 95% for seedlings with 10 or more first-order, lateral roots greater than 1 mm, and that were protected by tree shelters. The lowest percentage of survival was 78% for seedlings with 0-4 first-order, lateral roots, greater than 1 mm, and that were planted without tree shelters (Table 1) ($Pr>F = 0.07$). Seedlings protected by tree shelters had an average of 93% survival compared with 86% survival of seedlings without tree shelters (Table 2) ($Pr>F = 0.006$). Whether or not seedlings were undercut ($Pr>F = 0.81$) and whether or not the area was sprayed ($Pr>F = 0.37$) before planting did not make a statistically significant difference in survival.

Initial height

Average initial heights for seedlings that were undercut in the nursery were significantly greater than seedlings that were not undercut in the nursery (Table 3) ($Pr>F = 0.0004$).

Table 1.—Percentage of survival of underplanted 1-0 northern red oak seedlings by root class with and without tree shelters

Root class	Tree shelters	Survival (%)	Standard error of the mean	Sample size
0-4	tree shelters	92	2.4	89
0-4	no tree shelters	78	3.8	95
5-9	tree shelters	90	2.7	92
5-9	no tree shelters	90	2.5	98
10 or more	tree shelters	95	2.1	97
10 or more	no tree shelters	90	2.6	98

Table 2.—Percentage of survival of underplanted 1-0 northern red oak seedlings with and without tree shelters

Tree shelters	Survival (%)	Standard error of the mean	Sample size
tree shelters	93	1.4	278
no tree shelters	86	1.8	291

Table 3.—Average initial seedling heights, before underplanting, for 1-0 northern red oak undercut and not-undercut seedlings in the nursery

	Initial height	Standard error of the mean	Sample size
Not undercut	24.1 cm	0.67	15
Undercut	18.9 cm	0.54	15

Height growth

The greatest average height growth (7.5 cm) (Table 4) was for seedlings with 10 or more first-order, lateral roots greater than 1 mm (Pr>F = 0.0001). Undercut seedlings with 0-4 permanent, first-order, lateral roots had greater height growth than not-undercut seedlings. However, undercut seedlings with five or more permanent, first-order, lateral roots had less average height growth than not-undercut seedlings (Table 5) (Pr>F = 0.01).

Average height growth was also greatest for seedlings protected by tree shelters (Table 6) (Pr>F = 0.0001). Seedlings protected by tree shelters averaged 6.4 cm in height growth compared with seedlings without tree shelters, which averaged 2.8 cm of height growth.

Whether or not the area was sprayed before planting (Pr>F = 0.17) did not make a statistically significant difference in average height growth.

Table 4.—Average height growth (cm) for each root class of underplanted 1-0 northern red oak seedlings

Root class	Avg ht. growth (cm)	Standard error of the mean	Sample size
0-4	1.6	0.74	184
5-9	4.4	0.78	190
10 or more	7.5	0.70	195

Table 5.—Average height growth (cm) for each root class of 1-0 northern red oak seedlings undercut and not undercut in the nursery

Root class	Undercut	Avg ht. growth (cm)	Standard error of the mean	Sample size
0-4	not undercut	0.3 cm	1.28	94
0-4	undercut	2.9 cm	0.71	90
5-9	not undercut	5.1 cm	1.20	101
5-9	undercut	3.6 cm	0.97	89
10 or more	not undercut	9.2 cm	0.92	94
10 or more	undercut	6.0 cm	1.03	101

Table 6.—Average height growth (cm) for underplanted 1-0 northern red oak seedlings with and without tree shelters

Tree shelters	Avg ht. growth	Standard error of the mean	Sample size
tree shelters	6.4 cm	0.64	278
no tree shelters	2.8 cm	0.59	291

Competition

Competition is an important factor in the success or failure of red oak seedling establishment. Three components making up competition are number of competing tree seedlings and shrubs, height of competing tree seedlings and shrubs, and impact of the overstory (Kolb and Steiner 1989, Myers *et al.* 1989, Kolb *et al.* 1989).

Number of competing seedlings

The average total number of competing seedlings and shrubs by regeneration technique at the end of the establishment year (1991) are presented in Table 7. There was no significant difference in the number of competing tree seedlings and shrubs by regeneration technique for the first growing season (Pr>F = 0.21).

Table 7.—The number of competing seedlings and shrubs/ha for each regeneration technique

Regeneration technique	No. of competing shrubs & seedlings/ha	Standard error of the mean	Sample size
nat. regen. undisturbed	7,100	826	15
not undercut seedlings	6,300	723	15
undercut seedlings	6,900	929	15

The total number of competing seedlings and shrubs is just one factor that is important when looking at the number of competing tree seedlings and shrubs. The number of new competing tree seedlings and shrubs is also important because regeneration techniques may stimulate new competition. The average number of competing tree seedlings and shrubs that were less than 4 mm in ground-line diameter by regeneration technique at the end of the establishment year (1991) are presented in Table 8. This comparison indicates that none of the regeneration techniques stimulated a great increase in the number of new, competing tree seedlings and shrubs (Pr>F = 0.50).

Table 8.—The number of competing seedlings and shrubs/ha that were less than 4 mm in ground-line diameter for each regeneration technique

Regeneration technique	No. of new competing shrubs & seedlings/ha	Standard error of the mean	Sample size
not undercut seedlings	4,244	1,508	15
nat. regen. undisturbed	3,111	1,492	15
undercut seedlings	2,956	768	15

The average numbers of competing seedlings and shrubs at the end of the establishment year (1991) for the unsprayed and sprayed areas were 7,800/ha (s = 3,000/ha) (sample size: n = 48) and 4,500/ha (s = 2,500/ha) (n = 46), respectively. Spraying the area in the fall (1990) before planting in the spring (1991) reduced the competition by 42 percent (3,300 seedlings and shrubs/ha) (Pr>F = 0.0028). The average numbers of competing seedlings and shrubs that were less than 4 mm in ground-line diameter at the end of the establishment year (1991) for the unsprayed and sprayed areas were 1,573/ha (s = 2,647/ha) (n = 48) and 956/ha (s = 1,055/ha) (n = 46), respectively. Spraying before planting did not create conditions for regeneration of competing seedlings and shrubs because the number of seedlings and shrubs that were less than 4 mm in ground-line diameter did not increase significantly (Pr>F = 0.56).

Height of competing seedlings and shrubs

Comparisons were made of average seedling height between the underplanted red oak seedlings and the competition in each treatment area (Table 9). All treatment areas had competing seedlings and shrubs with an average height at the end of the growing season greater than red oak seedlings established during the first year. The treatments seem to have very little effect on the average height of the competing seedlings and shrubs (Pr>F = 0.56).

Table 9.—Comparison of average competing seedling heights with red oak seedling heights for natural regeneration undisturbed (control), for each root class of 1-0 northern red oak seedlings not undercut (SG), and for each root class of 1-0 northern red oak seedlings undercut (UP)

Technique		**Control**	**SG**	**UP**
Competition Avg ht. (cm)		45	41	42
Standard error of the mean		1.2	2.2	1.6
Sample size		792	707	772
1-0 Northern red oak with root class:				
0-4	avg. ht (cm)		22	21
	Standard error of the mean		1.6	2.8
	Sample size		94	90
5-9	avg. ht (cm)		26	22
	Standard error of the mean		1.4	0.9
	Sample size		101	89
10 or more	avg. ht (cm)		39	26
	Standard error of the mean		1.0	1.1
	Sample size		94	101

Overstory impact

To analyze the effect of overstory density on seedlings, linear regression was used to test the effect of average basal area on percentage of survival and average height growth. Seedlings protected by tree shelters were chosen, because they performed the best in survival and height growth. The tests indicated that overstory density had no major effect on percentage of survival ($r^2 = 0.042$) or average height growth ($r^2 = 0.003$).

DISCUSSION

Underplanted Seedling Performance

Based on first year results, the number of lateral roots (greater than 1 mm.) and planting in tree shelters seem to be important factors in establishing underplanted northern red oak seedlings. Planting in tree shelters significantly affected survival and average height growth. Seedlings planted in tree shelters had a 7% better survival rate than seedlings not in tree shelters. Tree sheltered seedlings had an average height growth of 128% more than seedlings not planted in tree shelters. Seedlings with 10 or more first-order lateral roots outperformed seedlings with 5-9 first-order lateral roots by 70%, and seedlings with 0-4 first-order lateral roots, by 369% in average height growth.

The response in survival and height growth of underplanted northern red oak seedlings the first year after planting may actually be related to the treatment that the seedlings received in the nursery. Studies by Schultz and Thompson (1991) have shown that survival and growth of northern red oak seedlings are strongly correlated with the number of permanent first-order lateral roots that the seedlings developed in the nursery. Seedlings planted in tree shelters outperformed seedlings without tree shelters in survival and height growth. This performance is consistent with studies conducted by Tuley (1985), Potter (1991), Teclaw and Isebrands (1991), and Minter *et al.* (1992). Trends in survival and height growth indicate that seedlings with 10 or more first-order lateral roots will outperform seedlings with 5-9 and 0-4 first-order lateral roots. This response is consistent with studies conducted by Schultz and Thompson (1991), who have shown that seedlings with six or more permanent first-order lateral roots generally have the best performance in survival and height growth. This performance is expected because of the size of the root system. The larger the root system the better the seedlings perform. Struve (1990) indicates that the number of first-order, lateral roots are important, because these roots form the basic framework for the new root network. The greater the number of permanent, first-order, lateral roots, the greater is the potential for growth.

Undercut seedlings tended to grow less in height than seedlings that were not undercut, especially seedlings with a larger number of first order lateral roots. This finding is opposite of what would be expected, but may result from the undercut seedlings being 21.6% smaller in initial height than seedlings that were not undercut. The difference in average height growth between the undercut and not undercut seedlings may be due to the difference in photosynthate allocation while the seedlings were in the nursery. Undercutting seedlings in the nursery, probably stimulated them to put photosynthate in excess of respiration into new root production; thereby reducing top growth and the bud component for the next year (i.e., establishment year, 1991). Because oak is a fixed grower (growth is set in the bud), the seedlings that were not undercut would have a greater potential for top growth during the first growing season in the field than seedlings that were undercut. This is consistent with Dickson (1991), where under less than favorable conditions, such as transplant shock, red oak seedlings stopped top growth and allocated photosynthate to root growth and storage.

Competition

Spraying the area with glyphosate herbicide before planting reduced the number of seedlings and shrubs competing with red oak regeneration by 42%, but did not accelerate growth of the underplanted red oak seedlings in the sprayed areas compared with the unsprayed areas. This lack of accelerated growth was not surprising because northern red oak is a fixed grower. Under less than favorable conditions caused by overstory and understory competition, lack of rain fall, and transplant shock, red oak will stop top growth and allocate photosynthate to root growth and storage (Dickson, 1991).

For the red oak seedlings to be a major component in the new stand, they will have to grow faster and be taller than the competition. The only red oak seedlings close in average height to the competition at the end of the establishment year were underplanted red oak seedlings that were not undercut and had 10 or more first-order lateral roots at the time of planting. The underplanted red oak seedlings that were not undercut and had 10 or more first-order lateral roots were 17% smaller than the competition.

The number of competing seedlings and overstory density had little effect on survival or height growth of northern red oak regeneration during the first growing season.

CONCLUSION

It is premature to prescribe a method for regenerating northern red oak based only on the first-growing season. Based on first-growing season results, however, protection by tree shelters and the number of lateral roots greater than 1 mm seem to be important factors in the survival and height growth of underplanted northern red oak seedlings. Trends in survival and height growth indicate that seedlings with 10 or more first-order, lateral roots might be the most successful in underplanting situations, compared with seedlings with fewer first-order, lateral roots. Underplanted seedlings protected by tree shelters performed better in height growth and survival than seedlings not protected by tree shelters. The seedlings in tree shelters are expected to continue this performance in height growth and survival until they have grown out the tops of the shelters. Based on first-year data, underplanting seedlings with large numbers of first-order, lateral roots and using tree shelters may be a viable solution to establishing northern red oak regeneration if such a system is economically feasible.

Data from the study show that a foliar application of glyphosate herbicide reduced the amount of vegetation competing with northern red oak regeneration. Greater survival and better growth is expected to be related to reduced competition. If greater survival and better growth are sustained for a significant time, then spraying the area may be an important part of establishing red oak regeneration.

Data from more than one year will be needed to prescribe suitable methods for regenerating northern red oak. But, data from the first-year of this study and studies conducted by other researchers indicate that the use of tree shelters (Tuley 1985, Potter 1991, Teclaw and Isebrands 1991, Minter *et al.* 1992) and planting northern red oak seedlings with 5 or more first-order, lateral roots, greater than 1 mm (Schultz and Thompson 1991) improve the chances of successfully establishing red oak regeneration.

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