EFFECTS OF SITE PREPARATION, SEEDLING QUALITY, AND TREE SHELTERS ON PLANTED NORTHERN RED OAKS[1]

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Abstract
Effects of site preparation, seedling quality, and tree shelters on planted northern red oaks were studied through field trials in southeastern Minnesota. Seedling survival, height and diameter growth were greater for seedlings planted under 10 square feet per acre of residual basal area compared to 47 square feet per acre. Chemical and mechanical site preparation increased seedling survival and growth over no site preparation. Seedlings with at least six first-order lateral roots had higher survival and diameter growth than nursery run seedlings. Tree shelters increased seedling height growth, but not diameter growth or survival.

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Oaks are among the most valuable hardwood timber species on a per acre basis in Minnesota and the mainstay of southeastern Minnesota's forest products industry. Equally important, acorns are an important food for many wildlife species, and in hilly terrain, oak woodlands protect water quality by serving as buffers between agricultural land and streams.

The oak-hickory forest type[3] is a pre-climax plant community occurring throughout the central hardwood forest where soil or slope exposure has delayed development of the climax forest (usually maple-basswood) or where fire routinely destroyed climax species. The oak-hickory forest type covers approximately 7 percent of all forest land in the state, but 64 percent of all forest land in southeastern Minnesota[4] (Miles and Chen 1992).

The current abundance of mature, even-aged red and white oak stands is an artifact of wildfires that are no longer common due to fire suppression (Abrams 1992, Crow 1988, Grimm 1984, Johnson 1993). Historically, fires maintained the oak component in Lake States forests by killing other tree species that had thinner bark or were unable to sprout back after fires (Crow 1988, Johnson 1993). Fires reduced understory competition and thinned the canopy creating improved light, moisture, and nutrient conditions for more fire resistant oak seedlings and stump sprouts. European settlement and the advent of fire suppression disrupted the normal disturbance regime of periodic fires, which in turn allowed other tree species to invade oak woodlands (Baughman and Jacobs 1992).

Minnesota's common oak species are intermediate in shade tolerance and cannot regenerate beneath a dense overstory or understory. For the last century stands have been converting through natural succession to more shade tolerant and/or faster growing tree species, which are of less value to the forest products industry and wildlife (Crow 1988, Nowacki et al. 1990). Harvesting, as well as losses to diseases, insects, and climatic stresses, have probably accelerated species conversion in these oak stands. The failure of oak species to regenerate following a harvest can be attributed to either the absence of adequate advance regeneration or the inability of oak seedlings that are present to respond rapidly and outgrow their competition once released (Crow 1988). Historically, oak forests were high-graded, a harvesting method where loggers cut only the highest quality trees. This harvesting method left a residual stand of poor quality trees that had little potential for developing into merchantable timber and they became the seed source for the next generation of trees. Additionally, the small canopy openings created by this harvesting method provided too little sunlight for oak species to regenerate (Baughman and Jacobs 1992).

Currently no known cultural methods will consistently establish advance northern red oak regeneration (Sander 1977). This problem has led forest managers to consider the use of artificial regeneration methods where natural oak regeneration is difficult to obtain (Johnson 1984). Forest managers and researchers have developed prescriptions for artificial regeneration of northern red oak in the central hardwoods region, however, these prescriptions have yet to be adequately tested in the Lake States (Teclaw and Isebrands 1991).

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3 The oak-hickory forest type is defined by the USDA Forest Service as forests in which northern red oak, white oak, bur oak or hickories, singly or in combination, comprise a plurality of the stocking (Miles and Chen 1992).

4 The central hardwoods unit is a 28-county region in southeastern Minnesota. Its boundaries are defined by the USDA Forest Service as the geographic distribution of the oak-hickory cover type in Minnesota (Clark and Hutchinson 1989).

We began this research project to evaluate current prescriptions for artificially regenerating northern red oak in southeastern Minnesota's Driftless Area[5] where the highest quality oak sites and largest area of high-quality oak forests are found.

Our research objectives were to:

1. Compare the growth response of planted northern red oak (*Quercus rubra* L.) seedlings and acorns to different site preparation treatments: mechanical, chemical, and control.
2. Compare the growth response and survival of nursery grown northern red oak seedlings with at least six first-order lateral roots[6] to nursery run seedlings.
3. Compare the growth and survival of northern red oak seedlings and acorns with and without tree shelters.

METHODS

Three research sites were chosen where treatments were to be replicated, then we inventoried overstory and understory vegetation, performed site preparation treatments in the understory, harvested the stands, performed post-harvest treatments to kill undesirable residual trees, removed slash from planting sites, planted seedlings and acorns, measured seedlings, and remeasured seedlings and understory vegetation at the ends of the next three growing seasons.

Research Site Selection

Three research sites were chosen from among 17 stands in the Richard J. Dorer Memorial Hardwood State Forest that the Minnesota Department of Natural Resources (MN DNR) identified as having superior qualities[7] for growing northern red oak and white oak (Anderson 1993). During the late spring and early summer of 1991, all 17 stands were evaluated by measuring a series of plots in each. The number of plots varied with stand size. Additional information about each stand was collected through personal interviews with the appropriate MN DNR District Forester.

- Species composition of the overstory had to meet the definition of a white oak - black oak - northern red oak forest cover type (SAF type 52), with northern red oak as the dominant overstory species (Eyre 1980).
- Stands had to meet the habitat type classification of either ArCi (red maple/nightshade) dry-mesic type or AsCa (sugar maple/blue cohosh) mesic type (Kotar 1991). These

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5 The Driftless Area is an island of unglaciated land, surrounded by glaciated land, covering approximately 10 million acres in southeastern Minnesota, northeastern Iowa, and southwestern Wisconsin. Roughly one-third of the Driftless Area is forested (Jacobs and Wray 1992).

6 First order lateral roots are lignified and measure at least 1 millimeter in diameter at their point of attachment to the taproot.

7 These stands were located by Ken Anderson and Ed Godel under contract to the MN DNR. Drawing from their personal experience and using the criteria developed by Arend and Scholz (1969), they ground-checked approximately 100 stands and defined these 17 as having superior qualities for regenerating northern red oak.

habitat types have excellent potential for growing northern red oak. This habitat type classification system, developed for the Driftless Area of southwestern Wisconsin, uses existing overstory and understory vegetation to characterize and classify site types of equal biological potential.

- Slope had to be gentle enough for mechanical site preparation treatments to be used. Aspect had to be north or east to signify a moist environment, compared with hotter and drier south- and west-facing slopes. Selected stands were on fairly level north- and east-facing shoulder or toe slopes.
- Soil had to be suitable for excellent timber growth. Information on soil characteristics was obtained from published soil surveys where available and by personal interviews with employees of the USDA Natural Resources Conservation Service. Soils on selected stands were derived from loess and were deep and well-drained with moderate permeability, high available water capacity, and moderate organic matter content. Site index was 70 or better for northern red oak and white oak (Jacobs and Wray 1992, Soil Survey of Houston County, Minnesota 1984).
- Stands had to be scheduled for harvest in the late fall of 1991 or winter of 1991-1992.

Only 2 of the 17 stands evaluated met the site selection criteria. The others were disqualified based on either their proposed date for harvesting or site conditions that did not meet the specified standards. The two stands that met all site selection criteria were at Money Creek in Houston County (Section 16, Township 104 North, Range 7 West) and at Trout Valley in Winona County (Section 4, Township 108 North, Range 9 West). The Trout Valley stand actually included two different stands, approximately equal in size, that were geographically separated by a small cove approximately 3/4 mile wide. Since there were differences in species composition, soil properties, and site quality between the two Trout Valley stands, they were divided into two separate research sites: Trout Valley East and Trout Valley West.

Selected stands had histories of high-grading; many trees were unmerchantable due to poor form. The understories were dominated by noncommercial species including elm (*Ulmus spp.*), black cherry (*Prunus serotina* Ehrh.), and hackberry (*Celtis occidentalis* L.).

Experimental Design

The experimental design was a generalization of the randomized block design called a split-plot design (Montgomery 1991). In a split-plot design, each block is divided into whole plots, which are further subdivided into subplots (also known as split plots). In this study each block was replicated once at each of three research sites. Research sites varied from 5 to 30 acres in size. Working with MN DNR district foresters, we located a rectangular three-acre block within each research site. All treatments took place within these blocks. Each block then was divided into three one-acre, whole plots that were approximately

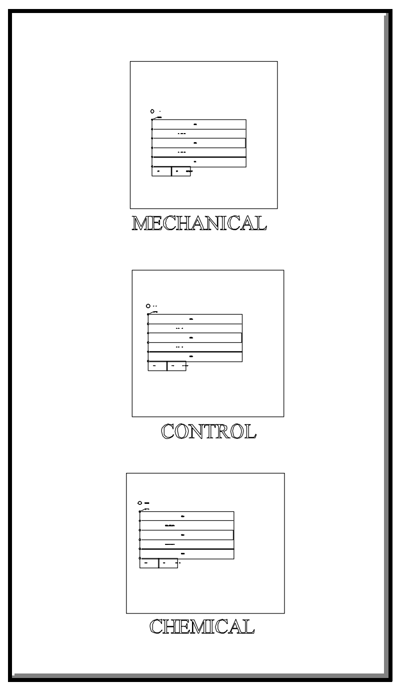

Figure 1 Schematic of a sample whole plot design showing site preparation treatments within a research block.

200 feet long on each side. Whole plots were located next to one another within each block, however they did not fully use a block. We left a buffer strip at least 66 feet wide between the whole plot boundary and the treatment area. Site preparation treatments (chemical, mechanical, and control) were randomly assigned to one-acre whole plots within each block at each research site (see Figure 1).

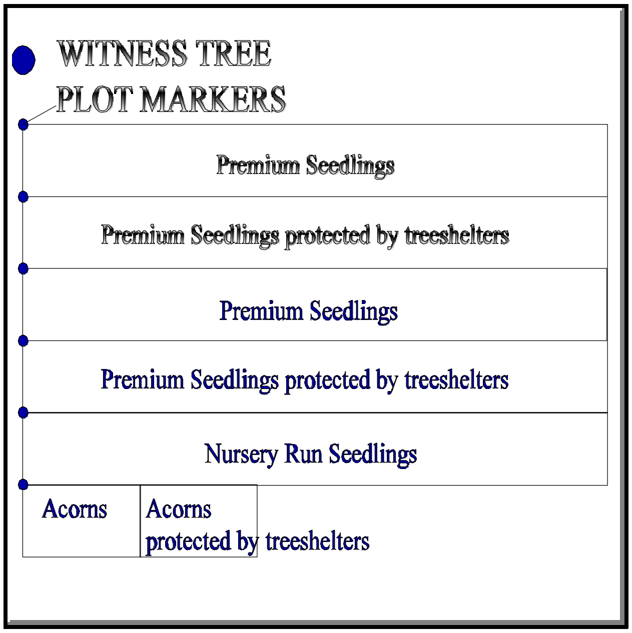

Figure 2. Schematic of subplot design showing planting stock types within a site preparation treatment whole plot.

Whole plots were further divided into five subplots for seedling trials and two subplots for acorn trials. There were two subplot replications of premium seedlings (30 seedlings per subplot), two subplot replications of premium seedlings protected by tree shelters (30 seedlings per subplot), and one subplot of nursery run seedlings (30 seedlings per subplot). Seedling types were randomly assigned to specific subplots in each site preparation treatment whole plot. To minimize site effects, subplot replicates were not allowed to be placed next to each other. Due to the limited area we were able to clear for planting, the acorn subplots were placed side by side and subplots were located wherever there was sufficient space for planting. There was one subplot for acorns (30 acorns per subplot) and one subplot for acorns protected by tree shelters (quills) (30 acorns per subplot) (see Figure 2).

<u>Site Preparation Treatments</u>

Site preparation treatments were performed to reduce competition from understory woody and herbaceous vegetation. Treatments included chemical, mechanical, and a control. Chemical and mechanical site preparation treatments were performed late in the summer of 1991.

The chemical treatment consisted of 2 quarts of Accord, 2 ounces of Oust, and Valent X-77[8] (a surfactant) in 10 gallons of water per acre. The herbicide mixture was applied in late August and early September of 1991 using a backpack mistblower. The mixture also included Bullseye[9], a blue spray pattern indicator, that enabled us to visually monitor coverage of the chemical treatment and drift. After the application was completed, we visually inspected the chemical treatment sites to insure that coverage was complete and that drift off the site had been kept to a minimum. Project staff applied the chemical treatments, however, different crews applied the chemicals at Trout Valley East, Trout Valley West, and Money Creek and did not always use the same mistblower.

Mechanical treatments were performed by a d-6 bulldozer and were completed by mid-

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8 Registered trademark product manufactured by Chevron.

9 Registered trademark product manufactured by Milliken chemicals.

August of 1991. As the bulldozer moved through a stand, it ran over small trees and shrubs in an attempt to destroy them by bending, breaking, or uprooting. The operator elevated the bulldozer blade approximately one foot above the ground to minimize the amount of soil being pushed by the blade. Mechanical treatments at Trout Valley East and West sites were performed by a different contractor from the one who applied mechanical treatments at the Money Creek site.

Before harvesting in October of 1991 at the Trout Valley sites, a "hack and squirt" operation was performed to kill all non-commercial tree species less than six inches in diameter at breast height. Trees were girdled with a chain saw then Tordon RTU[10] was applied to chain saw cuts with a backpack sprayer.

<u>Stand Harvesting</u>

The three research sites were commercially harvested during the late fall and early winter of 1991-1992. The MN DNR marked a small number of mature, high value hardwood trees (northern red oak, black oak, white oak, green ash (*Fraxinus pennsylvanica* Marsh.) and black walnut (*Juglans nigra* L.)) to be left in these stands as seed trees, although our research plan called for complete clearcutting. The harvesting operations removed 60 to 90 percent of the overstory trees larger than four inches diameter at breast height (dbh). The remaining overstory was composed primarily of seed trees that were left for natural regeneration purposes.

<u>Post-Harvest Treatments</u>

All residual stems larger than two inches in diameter, except for seed trees, were cut down by hand. However, it should be noted that site preparation treatments, harvesting, and post-harvest treatment did not destroy all of the undesirable species on these sites. Trees less than two inches in diameter that were present in large numbers before these treatments, including boxelder (*Acer negundo* L.) and hackberry (*Celtis occidentalis* L.), were relatively untouched by these treatments.

The harvesting and pre- and post-harvest operations left an enormous amount of slash in the research blocks. This was due in large part to unmerchantable trees that were felled and left to decompose. To simplify tree planting and subsequent measurement of the planting stock, a 50-foot by 75-foot space was cleared by hand in each site preparation treatment whole plot. Slash that was not removed or piled was limbed and knocked down to a height of no more than two feet.

<u>Planting Stock</u>

The seedlings, 2+0 bare-root, undercut northern red oak were supplied by the MN DNR General Andrews Nursery at Willow River, Minnesota. They were grown under standard nursery conditions from acorns collected in stands near Lewiston, Minnesota that had been selected for their high proportion of phenotypically superior trees. Using seedlings grown from acorns collected locally should have minimized some project variables and maximized seedling growth and survival (Teclaw and Isebrands 1991 and Johnson et al. 1986). Planting stock consisted of two seedling types: premium and nursery run. Premium seedlings had at least six first-order lateral roots and were graded by specially trained personnel at the nursery. Nursery run seedlings were standard northern red oak seedlings that the nursery commonly shipped to its field offices

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[10] Registered trademark product manufactured by Dow.

for planting.

The acorns used in this project were purchased from Maynard Underbakke Forestry Associates. According to Mr. Underbakke, these acorns had been collected early in the season (prior to September 5, 1991) from a limited number of open-grown trees and/or dominant and co-dominant trees from forest stands in or around Caledonia, Minnesota. It is unlikely that these acorns were collected from trees that meet the MN DNR's definition of a plus tree. The acorns were floated, sorted, and soaked for 20 minutes in a Benomyl[11] fungicide solution to retard mold while in cold storage. The acorns were stored in a cooler at a temperature of 34° to 36° degrees farenheit. Every two weeks the acorns were checked and the polyethylene bags were opened to allow for gas exchange and to drain any water that had accumulated in the bags.

Tree Planting

Snowy Pines Reforestation planted the seedlings in mid-April 1992. Slash and litter were raked away from each planting spot and then holes were dug using a hand-held, power auger. Seedlings were hand planted. They were placed against the side of the hole with the root collar flush to the ground line. Seedlings were planted at a spacing of 5 feet by 5 feet. This close spacing simplified relocation of seedlings necessary to collect growth and survival data, without creating additional unnecessary interspecific competition (Russell 1973).

The acorns were planted at the same time as the seedlings. One acorn was planted per seed spot. The acorns, drawn at random from the population, were planted by hand one to two inches deep with the embryo axis pointing down. A majority of the acorns that were planted had started to germinate as evidenced by a protruding radicle.

Tree Shelter Installation

Tree shelters were purchased from Treessentials Company, a local dealer of Tubex tree shelters. The tree shelters placed over seedlings were 4 feet in height and varied from 3.25 inches to 4 inches in diameter. The quills placed over acorns were 30 inches in height and 1 inch in diameter. The tree shelters were placed over the top of planted seedlings and were pressed into the ground to a depth of no more than one inch. Then each tree shelter was fastened to a white oak stake driven into the ground approximately two feet. The tree shelters were installed after seedling measurements were completed. This often occurred on either the same day as the seedlings were planted or the following day as time allowed. The tree shelters are photodegradeable and have a normal field life of five years in full sunlight (Potter 1991). Tree shelters can be removed once they begin to fall apart, however they should be left in place to support seedlings for at least full five years.

Northern Red Oak Seedling Inventory

Initial red oak seedling measurements were taken immediately after the seedlings were planted. Seedling height was measured to the nearest centimeter, from the ground line to the highest live bud, using a meter stick accurate to one-half centimeter. Seedling diameter was measured to the nearest millimeter, measured at 1 inch above the ground line, using a micrometer accurate to one-half millimeter.

Seedlings were remeasured in September 1992 (end of first full growing season), in

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11 Registered trademark product manufactured by Monsanto.

September 1993 (end of second full growing season), and again in September 1994 (end of third full growing season). Survival, height, diameter, and damage were recorded for each northern red oak seedling.

A seedling survived if it was alive at the end of the growing season when remeasurement took place. Seedlings that were alive but could not be measured due to obstructions, such as fallen trees or ground nesting wasps, were considered dead for the purposes of this study.

Damage was defined as the presence of well-defined damage that could easily be attributed to a specific cause: animal damage, biotic damage, and seedling mortality. Animal damage was defined as damage to the seedlings that was directly related to the activity of animals. This was mainly deer, rodent, and rabbit browse, however, it also included top dieback and mechanical damage to roots and stems directly related to this feeding. Biotic damage was defined as any damage to leaves or stem that could be directly related to insects, diseases, or weather. This category included top dieback; damaged, deformed, or wilted leaves; stem damage; and damage caused by weather or weather-related stress, such as seedlings or their tree shelters that were destroyed or made inaccessible for measurement by fallen branches or trees--the cause of which may have been wind, rain, or snowfall.

Competing Vegetation Inventory

Overstory and understory vegetation in each site preparation treatment whole plot was systematically inventoried during August and September of 1991 before the silvicultural treatments [site preparation, harvesting, and timber stand improvement (TSI) operations] were performed, and again in August 1992 and 1993. The purposes for these inventories were to determine the effect of site preparation treatments on competing vegetation and its regrowth and the effect of competing vegetation on planted red oak seedlings and acorns.

A nested plot design was used to inventory the understory vegetation on site preparation treatment whole plots systematically. Understory vegetation plots consisted of a center plot and six satellite plots in each site preparation treatment whole plot. Satellite plot centers were located at 60 degree intervals (starting at north) at a distance of one chain from the center plot. The center plot in each site preparation treatment whole plot was marked with a wooden stake, a 12-inch metal spike, and a wire flag. The center of each satellite plot was marked with a wire flag. Center plot location varied according to the size and shape of the site preparation treatment whole plot; however, in each case the center plot was located as close as possible to the actual center of the site preparation treatment whole plot. The center and satellite plots were forty-seven square feet (1/300 acre) in size. One quadrant of a 6.8 foot radius plot, the northeast quadrant of each plot, was used to inventory the understory vegetation. Since the inventory design was a systematic random selection, there was no need to randomly select the plot quadrant (Figure 3).

Silvicultural treatments (site preparation, harvesting, and TSI), especially the mechanical site preparation treatment, so disturbed the soil that in many cases the plot center markers had disappeared altogether. Therefore, we were forced to rely on compass and distance measurements to relocate some of the understory vegetation plots. This may have inadvertently led to inaccurate relocation of some understory vegetation plots.

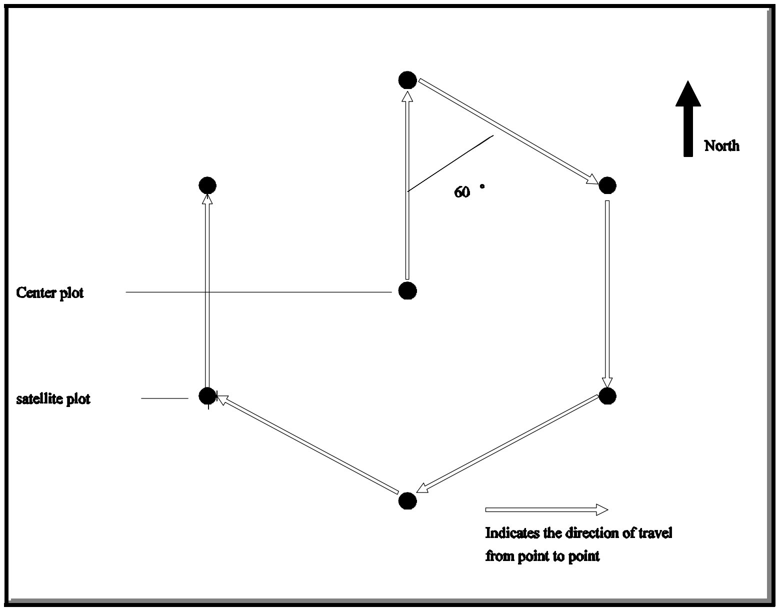

Figure 3 Diagram of the nested plot design used to survey the vegetation in the understory treatment and control areas.

Overstory species composition data were collected using a 10 BAF variable radius plot taken at the center plot. Tree species and diameter to the nearest two inches were recorded for all “in” trees. Understory species composition data were collected at each plot. These data included the species and height to the nearest one foot of all tree seedlings less than one inch in diameter at breast height, the species and height to the nearest one foot of all shrubs, an ocular estimate of the percentage of the ground covered by each of the four most prevalent herbs and forbs, and an ocular estimate of the percentage of the ground covered by the foliage of all herbs and forbs.

Statistical Analysis Methods

Seedling survival and growth data were analyzed using the SAS System for Windows release 6.11[12]. The data were broken into three categories: initial and annual height and height growth, initial and annual diameter and diameter growth, and seedling survival. The data were analyzed using a general linear means test. Unequal variance was a major problem with the seedling data because the height growth of the premium seedlings protected by tree shelters greatly exceeded the height growth of both the premium and nursery run seedlings. This difference in the rate of height growth had to be factored out before an analysis of variance test could be applied and meaningful results obtained. Power transformations are normally used to adjust for unequal variance. However, power transformations were problematic for the seedling growth data since a large number of seedlings had negative growth due to dieback and browsing. Since power transformations cannot accept negative data, the data were analyzed using the inverse of the variance as a weight. The seedling data were analyzed using a split-plot analysis of

[12] SAS System for Windows, release 6.11, is a registered trademark product produced by SAS Institute Incorporated.

variance by SAS's general linear means process. Where the analysis of variance indicated that there were significant differences in the data, a least squares means test was performed to determine exactly what those differences were. Additionally, since there were initial differences in the seedling diameter and height data, the seedling diameter and height growth data were analyzed for covariance against initial seedling height and diameter.

Overstory and understory data were analyzed using Statistix 4.0, a statistical analysis software package for microcomputers[13]. These data were divided into four categories: basal area per site preparation treatment whole plot, number of woody stems per understory vegetation plot, mean height of all woody stems per understory vegetation plot, and percent ground cover of all non-woody vegetation per understory vegetation plot.

The number of woody stems and percent ground cover data were analyzed using data from individual understory vegetation plots, however the mean stem height data were averaged for all stems on each understory vegetation plot. First the data were analyzed for unequal variance using Bartlett's test of equal variance. Where the analysis showed unequal variance for the basal area, number of woody stems per plot, and mean stem height data, the natural log of the data was analyzed. Where the analysis showed unequal variance for the percent ground cover data, a natural log transformation was performed and the data were then analyzed. Each data category was analyzed using a split-plot analysis of variance test to determine if there were any differences between site preparation treatment whole plots. Where the analysis of variance tests indicated there were significant differences in the data, a least significant difference test was performed to compare any and all possible contrasts between treatment means.

RESULTS

Our analysis evaluated the effects on red oak seedling growth from research blocks, site preparation treatments, planting stock types, and tree shelters.

Characterizing the Research Blocks

The overstory in all three research blocks prior to harvest and site preparation was dominated by a mixture of red oaks [northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), and pin oak (*Quercus palustris* Muench.)] and white oaks [white oak (*Quercus alba* L.) and bur oak (*Quercus macrocarpa* Michx.)]. An analysis of the diameter distribution of overstory tree species showed that 69 percent of all trees 12 inches dbh or larger were either red or white oaks, while only 37 percent of all trees less than 12 inches dbh but greater than 1 inch dbh were red or white oaks. The other major overstory species were elm, basswood, and hackberry.

The mean basal area over all three research blocks was 83 square feet per acre. An analysis of variance showed there was no statistically significant difference in the initial overstory mean basal area between research blocks (Table 1). After harvesting there were many more residual trees left standing than expected, resulting in variable crown cover between the research blocks, although an analysis of variance showed there was no statistically significant difference in

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13 Statistix 4.0 is a registered trademark product produced by Analytical Software.

the overstory mean basal area between research blocks following the harvest. After harvesting at Money Creek, the residual stand closely resembled a shelterwood or selection harvest with approximately 50 percent of the basal area removed. The loggers removed at least 90 percent of the basal area at the Trout Valley sites.

Table 1. Mean basal area by research block and year.

	BASAL AREA (square feet/acre)		
RESEARCH BLOCKS	**1991**	**1992**	**1993**
Money Creek	93	47	47
Trout Valley East	77	7	7
Trout Valley West	73	10	10

At the end of the third growing season (1994), planted red oak seedling survival was lowest at Money Creek (63.9 percent) and highest at Trout Valley East (84 percent). This was a significant decrease from previous years. There was relatively little difference in seedling survival between blocks at the ends of the first growing season, when survival ranged from 99.3 percent to 100 percent, and the second growing season, when survival ranged from 94.2 percent to 96.2 percent (Table 2).

Table 2. Mean percent survival of planted red oak seedlings by research block and year.

	SEEDLING SURVIVAL (%)		
RESEARCH BLOCKS	**1992**	**1993**	**1994**
Money Creek	99.3	94.2	63.9
Trout Valley East	99.8	95.6	84.0
Trout Valley West	100.0	96.2	72.2

Initially there was no statistically significant difference in mean stem height of planted red oak seedlings among the research blocks (Table 3). However, at the end of the third growing season (1994), mean stem height was significantly greater at Trout Valley West than at Money Creek. Mean stem height at Trout Valley East was not significantly different from either Trout Valley West or Money Creek.

Table 3. Mean stem height of planted red oak seedlings by research block and year.

	SEEDLING HEIGHT (inches)	
RESEARCH BLOCKS	**Initial Height Spring 1992**	**Final Height Fall 1994**
Money Creek	10.3 [a]	29.8 [b]
Trout Valley East	10.1 [a]	33.8 [ab]
Trout Valley West	10.4 [a]	36.0 [a]

NOTES:

[1] Seedling heights that were not significantly different between research blocks within a year ($p > 0.05$) share a common superscript letter.

Initially there was no statistically significant difference in mean stem diameter of planted red oak seedlings among research blocks. However, at the end of the third growing season (1994), mean stem diameter of seedlings at Trout Valley East and Trout Valley West was significantly greater than at Money Creek (Table 4).

Table 4. Mean stem diameter of planted red oak seedlings by research block and year.

	SEEDLING DIAMETER (inches)	
RESEARCH BLOCKS	**Initial Diameter Spring 1992**	**Final Diameter Fall 1994**
Money Creek	.19 [a]	.26 [b]
Trout Valley East	.19 [a]	.30 [a]
Trout Valley West	.19 [a]	.31 [a]

NOTES:

[1] Mean stem diameters that were not significantly different between research blocks within a year ($p > 0.05$) share a common superscript letter.

Characterizing Site Preparation Treatments

There were differences in competing vegetation and red oak seedling growth based on site preparation treatments.

Competing Vegetation

The understory data have three components: tree seedlings (advance natural regeneration), shrubs, and herbs. The most abundant tree species recorded in these plots (elm, cherry, and hackberry) accounted for 83 percent of all advance regeneration. Red and white oak seedlings were found on only 44 percent of the understory vegetation plots and accounted for fewer than 4 percent of the total number of woody stems per acre (Table 5). The shrub layer was dominated by hazel (*Corylus spp.*), prickly gooseberries (*Ribes spp.*), prickly ash (*Zanthoxylum* *americanum* Mill.), and dogwood (*Cornus spp*.) (Table 6.) The herb layer was dominated by blackberry (*Rubus spp*.), interrupted fern (*Osmunda Claytoniana* L.), maiden-hair fern (*Adiantum padatum* L.), stinging nettle (*Urtica dioica* L.), and sweet cicely (*Osmorhiza claytoni* Michx.) (Table 7).

Table 5. Mean tree seedling stems per acre by species, research block, and year.

SPECIES	BLOCK	MEAN TREE STEMS PER ACRE		
		1991	1992	1993
ash *(Fraxinus spp.)*	Money Creek	0	0	0
	Trout Valley East	0	147	0
	Trout Valley West	0	0	0
aspen	Money Creek	0	0	0
	Trout Valley East	0	0	294
	Trout Valley West	0	1,762	0
basswood	Money Creek	0	0	0
	Trout Valley East	0	294	441
	Trout Valley West	734	0	441
boxelder	Money Creek	147	1,762	1,322
	Trout Valley East	1,762	2,203	2,203
	Trout Valley West	587	587	1028
bur oak	Money Creek	147	0	0
	Trout Valley East	0	587	147
	Trout Valley West	0	0	0
cherry (*Prunus spp.*)	Money Creek	3,377	1,468	3,084
	Trout Valley East	1,468	4,112	2,937
	Trout Valley West	7,195	3,818	2,349
elm (*Ulmus spp.*)	Money Creek	4,699	3,818	3,377
	Trout Valley East	3,818	587	881
	Trout Valley West	3,377	147	441
hackberry	Money Creek	3,084	4,846	1,322
	Trout Valley East	4,846	2,056	3,084
	Trout Valley West	3,818	734	587
hickory (*Carya spp.*)	Money Creek	734	0	441
	Trout Valley East	0	441	147
	Trout Valley West	147	0	294
red oak	Money Creek	0	441	147
	Trout Valley East	441	1,322	147
	Trout Valley West	441	441	734
white oak	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	441	0	0

Table 6. Mean woody shrub stems per acre by species, research block, and year.

SPECIES	BLOCK	MEAN SHRUB STEMS PER ACRE 1991	1992	1993
buckthorn	Money Creek	0	294	0
	Trout Valley East	294	0	0
	Trout Valley West	2,790	881	881
dogwood *(Cornus spp.)*	Money Creek	0	1,762	0
	Trout Valley East	1,762	3,524	587
	Trout Valley West	1,762	587	0
hazel (*Corylus spp.*)	Money Creek	3,524	1,322	294
	Trout Valley East	1,322	7,195	147
	Trout Valley West	2,056	6,608	3,671
leatherwood	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	294	0	0
prickly ash	Money Creek	1,909	0	147
	Trout Valley East	0	587	0
	Trout Valley West	5,580	2,937	3,084
(Ribes spp.)	Money Creek	1,615	1,909	4,846
	Trout Valley East	1,909	6,461	5,139
	Trout Valley West	14,390	16,010	3,524
sumac	Money Creek	0	0	587
	Trout Valley East	0	0	1,909
	Trout Valley West	147	0	147
(Viburnum spp.)	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	147	0	0

Table 7. Frequency (percent of plots) of herbaceous species on understory vegetation plots by research block and year.

		FREQUENCY (%)		
SPECIES	BLOCK	1991	1992	1993
anemone (*Anemone spp.*)	Money Creek	5	5	43
	Trout Valley East	0	0	0
	Trout Valley West	0	0	0
baneberry	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	0	43	0
bedstraw (*Galium spp.*)	Money Creek	0	10	19
	Trout Valley East	0	5	10
	Trout Valley West	0	38	33
blackberry (*Rubus spp.*)	Money Creek	33	33	62
	Trout Valley East	10	57	43
	Trout Valley West	10	33	67
bloodroot	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	0	0	5
blue cohosh	Money Creek	0	0	0
	Trout Valley East	0	5	0
	Trout Valley West	0	0	0
burdock *(Arctium spp.)*	Money Creek	0	0	0
	Trout Valley East	0	0	5
	Trout Valley West	0	0	0
false solomon's seal	Money Creek	0	0	5
	Trout Valley East	0	5	0
	Trout Valley West	0	0	0
ferns	Money Creek	33	10	14
	Trout Valley East	29	14	5
	Trout Valley West	43	10	38
fleabane	Money Creek	0	5	29
	Trout Valley East	0	0	48
	Trout Valley West	0	5	5
frost grape	Money Creek	5	5	0
	Trout Valley East	0	10	14
	Trout Valley West	0	14	10

Table 7 (cont.). Frequency (percent of plots) of herbaceous species on understory vegetation plots by research block and year.

SPECIES	BLOCK	FREQUENCY (%) 1991	1992	1993
geranium	Money Creek	0	90	0
	Trout Valley East	0	24	0
	Trout Valley West	0	29	0
goldenrod	Money Creek	0	0	0
	Trout Valley East	0	0	5
	Trout Valley West	0	0	5
grass (*Poa spp.)*	Money Creek	0	0	0
	Trout Valley East	0	5	0
	Trout Valley West	0	0	0
greenspire	Money Creek	0	5	0
	Trout Valley East	0	0	0
	Trout Valley West	0	0	0
hog peanut	Money Creek	5	5	10
	Trout Valley East	0	5	24
	Trout Valley West	0	5	10
horseweed	Money Creek	0	0	24
	Trout Valley East	0	5	19
	Trout Valley West	0	5	29
jack-in-the-pulpit	Money Creek	0	5	0
	Trout Valley East	0	5	0
	Trout Valley West	0	0	0
jewelweed	Money Creek	0	0	10
	Trout Valley East	0	0	0
	Trout Valley West	0	0	14
lamb’s quarters	Money Creek	0	5	0
	Trout Valley East	0	10	0
	Trout Valley West	0	5	0
lopseed	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	0	0	5
mullein	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	0	10	5
poison ivy	Money Creek	5	0	5
	Trout Valley East	0	5	5
	Trout Valley West	24	24	0

Table 7 (cont.). Frequency (percent of plots) of herbaceous species on understory vegetation plots by research block and year.

		FREQUENCY (%)		
SPECIES	**BLOCK**	**1991**	**1992**	**1993**
ragweed	Money Creek	0	0	0
	Trout Valley East	0	5	0
	Trout Valley West	0	0	0
strawberry *(Fagaria spp.)*	Money Creek	0	0	0
	Trout Valley East	0	0	0
	Trout Valley West	0	0	5
sticktight *(Lappula spp.)*	Money Creek	0	0	0
	Trout Valley East	0	0	33
	Trout Valley West	0	0	10
stinging nettle	Money Creek	38	38	38
	Trout Valley East	29	67	38
	Trout Valley West	10	5	14
sweet cicely	Money Creek	62	48	14
	Trout Valley East	0	38	0
	Trout Valley West	0	19	0
thistle (Cirsium spp.)	Money Creek	0	5	33
	Trout Valley East	0	5	33
	Trout Valley West	0	10	48
tic trefoil	Money Creek	14	33	38
	Trout Valley East	0	24	14
	Trout Valley West	0	29	33
white snakeroot	Money Creek	0	0	48
	Trout Valley East	0	43	76
	Trout Valley West	0	23	43
woodbine	Money Creek	10	29	5
	Trout Valley East	48	38	33
	Trout Valley West	67	67	48

Prior to the harvest and site preparation treatments, there were no significant differences in the mean number of woody stems (understory tree seedlings and shrubs) per acre between site preparation treatment whole plots. In the year following harvest and site preparation, the mean number of woody stems declined significantly in the chemical treatment plots, did not significantly change in the mechanical treatment plots, and increased significantly in the control plots. Two years after the harvest and site preparation treatments, there was a general decline in the number of stems per acre for all species except boxelder, which nearly doubled, and northern red oak, which increased slightly. The chemical site preparation treatment, however, was the only treatment that significantly reduced the number of stems per acre (Table 8). The general decline in the mean number of woody understory stems coincided with an increase in the mean percent ground cover of herbaceous vegetation (see Tables 8 and 9).

Table 8. Mean number of woody stems (tree seedlings and shrubs in the understory) per acre by site preparation treatment.

SITE PREPARATION TREATMENTS	STEMS PER ACRE[1]		
	1991	1992	1993
Control	10,518[a]	15,273[a]	8,734[a]
Chemical	13,127[a]	5,942[a]	3,980[a]
Mechanical	9,685[a]	13,014[a]	7,902[a]

NOTES:

1 Stems per acre measurements per site preparation treatment that did not differ significantly ($p > 0.05$) within a given year share a common superscript letter.

Table 9. Mean percent ground cover of herbaceous vegetation by site preparation treatment and year.

SITE PREPARATION TREATMENTS	GROUND COVER (%)[1]		
	1991	1992	1993
Control	19[a]	22[a]	66[a]
Chemical	37[a]	8[b]	58[a]
Mechanical	33[a]	22[a]	70[a]

NOTES:

1 Percent ground cover measurements that were significantly different ($p > 0.05$) between treatments within a given year share a common superscript letter.

Prior to the site preparation treatments, mean height of woody stems (understory tree seedlings and shrubs) did not differ significantly between site preparation treatment whole plots. At the end of the first growing season, mean height of woody stems was significantly greater in control plots than in chemical and mechanical site preparation treatment plots, but at the end of the second full growing season, there again were no significant differences in mean height of woody stems among site preparation treatment plots (Table 10).

Table 10. Mean stem height of woody understory (tree seedlings and shrubs) by site preparation treatment and year.

SITE PREPARATION TREATMENTS	STEM HEIGHT (inches)		
	1991	1992	1993
Control	30.7[a]	33.9[b]	45.3[a]
Chemical	34.3[a]	25.2[a]	35.0[a]
Mechanical	27.6[a]	23.2[a]	39.4[a]

NOTES:

[1] Mean stem heights that were not significantly different ($p > 0.05$) between site preparation treatments within a given year share a common superscript letter.

Seedling Survival and Growth

There was relatively little difference in planted red oak seedling survival at the ends of both the first growing season, where survival ranged from 99.3 percent to 100 percent, and the second growing season, where survival ranged from 94.9 percent to 96.2 percent (Table 11). At the end of the third growing season, however, survival was lowest in the control plots (53.7 percent) and highest in the chemical treatment plots (88.2 percent).

Table 11. Mean percent survival of planted red oak seedlings by site preparation treatment and year.

	SEEDLING SURVIVAL (%)		
SITE PREPARATION TREATMENTS	1992	1993	1994
Control	99.8	94.9	53.7
Chemical	99.3	96.2	88.2
Mechanical	100.0	94.9	78.2

Initially the mean stem height of planted red oak seedlings was significantly greater in control plots than in chemical and mechanical site preparation plots (Table 12). However, at the end of the third growing season (1994), there was no significant difference in mean stem height of planted red oak seedlings between the control, chemical, and mechanical treatments.

Table 12. Mean stem height of planted red oak seedlings by site preparation treatment and year.

SITE PREPARATION TREATMENTS	SEEDLING HEIGHT (inches) Initial Height Spring 1992	Final Height Fall 1994
Control	10.6 [a]	33.2 [a]
Chemical	10.0 [b]	32.8 [a]
Mechanical	10.2 [b]	33.5 [a]

NOTES:

[1] Mean stem heights that were not significantly different between site prepration treatments within a year (p > 0.05) share a common superscript letter.

Initially the mean stem diameter of planted red oak seedlings in the control plots was significantly greater than in the chemical and mechanical site preparation treatment plots. However, by the end of the third growing season, mean stem diameter of planted red oak seedlings in chemical treatment plots was significantly greater than in the control and mechanical treatment plots (Table 13).

Table 13. Mean stem diameter of planted red oak seedlings by site preparation treatment and year.

SITE PREPARATION TREATMENTS	SEEDLING DIAMETER (inches) Initial Diameter Spring 1992	Final Diameter Fall 1994
Control	.20 [a]	.26 [b]
Chemical	.19 [b]	.32 [a]
Mechanical	.19 [b]	.29 [b]

NOTES:

[1] Mean diameters that were not significantly different between site preparation treatments within a year (p > 0.05) share a common superscript letter.

Planting Stock Types

Survival of planted red oak seedlings was 99% after one year, 94-95% after two years, and 72-74% after three years. There were no significant differences in survival rates among seedling types after three years (Table 14).

Table 14. Mean percent survival of planted red oak seedlings by seedling type and year.

	SEEDLING SURVIVAL (%)		
SEEDLING TYPE	**1992**	**1993**	**1994**
Nursery Run	99.6	94.4	72.6
Premium	99.8	95.9	74.3
Premium W/ Shelter	99.6	95.9	73.0

The germination rates of the planted acorns was unexpectedly low; approximately 34 percent of the acorns germinated and survived to the end of the first growing season. This result was quite different from the greenhouse trials in which 87 percent of the acorns germinated and survived for at least one month. By the end of the second growing season, only 19 percent of the planted acorns were still alive. Because the germination and survival rates among the planted acorns was so poor, we determined that no useful information could be gained from so small a sample and deleted the acorns from this study.

Initially the premium seedlings (both with and without tree shelters) were significantly taller than the nursery run seedlings (Table 15). By the end of the third growing season (1994), premium seedlings with tree shelters were significantly taller than both premium seedlings without tree shelters and nursery run seedlings.

Table 15. Mean stem height of planted red oak seedlings by seedling type and year.

	SEEDLING HEIGHT (inches)	
SEEDLING TYPE	**Initial Height Spring 1992**	**Final Height Fall 1994**
Nursery Run	8.7 [b]	23.5 [b]
Premium	10.7 [a]	27.1 [b]
Premium W/ Shelter	10.6 [a]	48.8 [a]

NOTES:

[1] Mean seedling heights that were not significantly different between seedling types within a year ($p > 0.05$) share a common superscript letter.

Initially the diameter of premium seedlings (both with and without tree shelters) was significantly greater than the nursery run seedlings (Table 16). By the end of the third growing season (1994), premium seedlings (both with and without tree shelters) continued to have a significantly greater diameter than nursery run seedlings.

Table 16. Mean stem diameter of planted red oak seedlings by seedling type and year.

	SEEDLING DIAMETER (inches)	
SEEDLING TYPE	**Initial Diameter Spring 1992**	**Final Diameter Fall 1994**
Nursery Run	.17 [b]	.27 [b]
Premium	.20 [a]	.30 [a]
Premium W/ Shelter	.20 [a]	.30 [a]

NOTES:

[1] Mean diameters that were not significantly different between seedling types within a year ($p > 0.05$) share a common superscript letter.

Seedling mortality was caused mainly by animal damage. Deer browse was the main problem and that was almost strictly confined to premium seedlings and nursery run seedlings without tree shelters. Each of the seedling types showed signs of deer browsing, ranging from 10 to 17 percent of the live seedlings in 1993. Mice and voles, however, caused the most serious damage. They chewed through tree shelters, then built nests and fed on the stems, girdling the seedlings. Approximately 4 percent of the premium seedlings with tree shelters were killed this way in 1993.

SUMMARY OF RESULTS

Among the most interesting, and least expected, results were the differences in red oak seedling growth and survival associated with different residual crown covers following logging at the Trout Valley and Money Creek sites. Although harvest specifications called for all three research sites to be clearcut with only specific seed trees left to promote natural regeneration, the logger at Money Creek left many more trees standing because they were unmerchantable. As a result, planted red oak seedlings at Money Creek were growing in overstory shade comparable to a shelterwood harvest (47 ft^2/ac residual basal area) in contrast to planted red oak seedlings at Trout Valley East and West that were growing in overstory shade comparable to a seed tree harvest (7 to 10 ft^2/ac residual basal area). After three growing seasons, the mean height and diameter of planted red oak seedlings were significantly less at Money Creek than at Trout Valley East and West. This is especially significant since Money Creek was originally rated as the best of the three sites for producing oaks. Survival of planted red oak seedlings was also lower (63.9%) at Money Creek than at Trout Valley West (72.2%) and East (84.0%) after three years. It appears that the amount of residual canopy cover at the Money Creek site had a negative effect on the survival and diameter growth of the planted seedlings. Since this was an aberration that we did not plan or test for, it is difficult to draw any definite conclusions. However, these results are consistent with the results of other studies that have looked at planting red oak seedlings under different harvesting treatments (Teclaw and Isebrands 1991).

Three years after the site preparation treatments:

- Stems per acre of woody understory competition was highest on control plots (8,734 stems/acre), intermediate on mechanical treatment plots (7,902 stems/acre), and lowest on chemical treatment plots (3,980 stems/acre), although these differences were not statistically significant.
- Mean stem height of woody understory competition was highest on control plots (45.3 inches), intermediate on mechanical treatment plots (39.4 inches), and lowest on chemical treatment plots (35.0 inches).
- Percent ground cover of herbaceous vegetation was highest on mechanical treatment plots (70%), intermediate on control plots (66%), and lowest on chemical treatment plots (58%), although these differences were not statistically significant.

As understory competition decreased, oak seedling survival and diameter growth (but not height growth) increased. Three years after site preparation treatments:

- Survival of planted red oak seedlings was highest on the chemical treatment plots (88.2%) where understory competition was lowest, intermediate on mechanical treatment plots (78.2%), and lowest on control plots (53.7%) were competition was highest.
- Mean stem diameter of planted red oak seedlings was significantly higher on chemical treatment plots (.32 inches) than on mechanical treatment plots (.29 inches) and control plots (.26 inches). In fact mean stem diameters of premium and nursery run seedlings were significantly larger on the chemical treatment plots than on the control plots despite the fact that those seedling diameters were initially larger on the control plots than on the chemical and mechanical treatment plots.
- Mean stem height of planted red oak seedlings was highest on mechanical treatment plots (33.5 inches), intermediate on control plots (33.2 inches), and lowest on chemical treatment plots (32.8), although these differences were not statistically significant.

Where competition was low (chemical treatment), the ratio of seedling height growth to diameter growth was lowest for all of the planting stock types. However where competition was high (control treatment), the ratio of seedling height growth to diameter growth was highest. This response by seedlings to reallocate growth either to stem or height increment due to competition for light and root interference has been documented by Kolb and Steiner (1989), Kolb, Bowersox, and McCormick (1990), and Weiner and Thomas (1992).

Because the survival rate of planted acorns was extremely poor (19% at the end of the second growing season), they were removed from the study.

At the end of the third growing season, the stem diameter of premium red oak seedlings was significantly larger than nursery run seedlings, but there were no significant differences in survival or height between these seedling grades. Ruehle and Kormanik (1986) have shown that for northern red oak, the number of first-order lateral roots on bareroot nursery seedlings was significantly correlated with height ($r = 0.68$) and stem diameter ($r = 0.70$). This agrees with results from Schultz and Thompson (1991) and Kormanik and Muse (1986) which indicated that seedlings with a greater initial number of first-order lateral roots had better survival rates and greater height and diameter growth.

At the end of the third growing season, mean stem height of premium rad oak seedlings protected by tree shelters was significantly greater than unprotected premium and nursery run seedlings, but tree shelters did not affect red oak seedling diameter growth or survival. The increased height growth may be due in large part to an increase in the number of annual flushes and a reallocation of growth from branches and stem diameter to the terminal leader (Lantagne, Ramm, and Dickman 1990 and Minter, Myers, and Fischer 1992). However, some of the increase in height growth may also be attributed to a decrease in deer browse and top dieback (Lantagne, Ramm, and Dickman 1990, and Zastrow and Marty 1991). It is important to note that the increased height growth of the seedlings seems to come at the expense of seedling caliper growth. Seedlings grown in tree shelters tend to have a columnar growth form with very little variation in stem diameter, as opposed to unprotected seedlings that typically have a tapered stem (Potter 1991). Additionally, seedlings that are grown in tree shelters are not windfirm and may need to be supported by the tree shelter for up to five years after planting and installation before they can be removed (Potter 1991). Tree shelters in our study prevented deer browsing, but contributed to more rodent damage.

CONCLUSIONS AND RECOMMENDATIONS

Since oak seedling survival, stem diameter, and height were significantly better under a 10% residual canopy cover than under a 47 percent residual canopy cover, we recommend leaving a canopy cover closer to 10 percent than to 50 percent. Other studies have shown acceptable oak seedling survival and growth with a 25 percent canopy cover by mature trees.

A site preparation method, either chemical or mechanical, can increase seedling survival and subsequent growth, although a financial analysis of the options would be beneficial to help make a decision. A simple analysis shows that a site preparation treatment would cost in the range of 10 to 18 cents per seedling, based on planting 680 seedlings per acre. This is approximately the same cost to replant fully one-third of the seedling at the end of the third year. This assumes a desired survival rate of at least 85 percent at the end of the third growing season and a seedling and hand planting cost of at least 37[14] cents a seedling.

We recommend the purchase and use of seedlings with at least six first-order, lateral roots. This study and others have shown that seedlings with larger, more fibrous root systems often have better survival and growth. A financial analysis of costs for different grades of seedlings compared to their survival and growth would be helpful.

While tree shelters were effective in protecting trees from animal damage and increasing seedling height growth, their high cost ($4.65 per seedling installed) may make their use unprofitable unless severe animal damage requires their use.

These plots should be remeasured again in the future to further evaluate the longer-term impacts of site preparation, seedling types, and tree shelters on oak survival and growth. These management techniques must pay for themselves over the whole rotation. The use of herbicides and bulldozers for site preparation are drastic measures that influence other biota as well as soil and water characteristics of the site. The impacts of such site preparation techniques on these other resources need further study.

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[14] All costs listed are based on either state average cost set by the USDA Farm Service Agency or state maximum costs set by the Minnesota DNR in their Stewardship Incentives Program docket.

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