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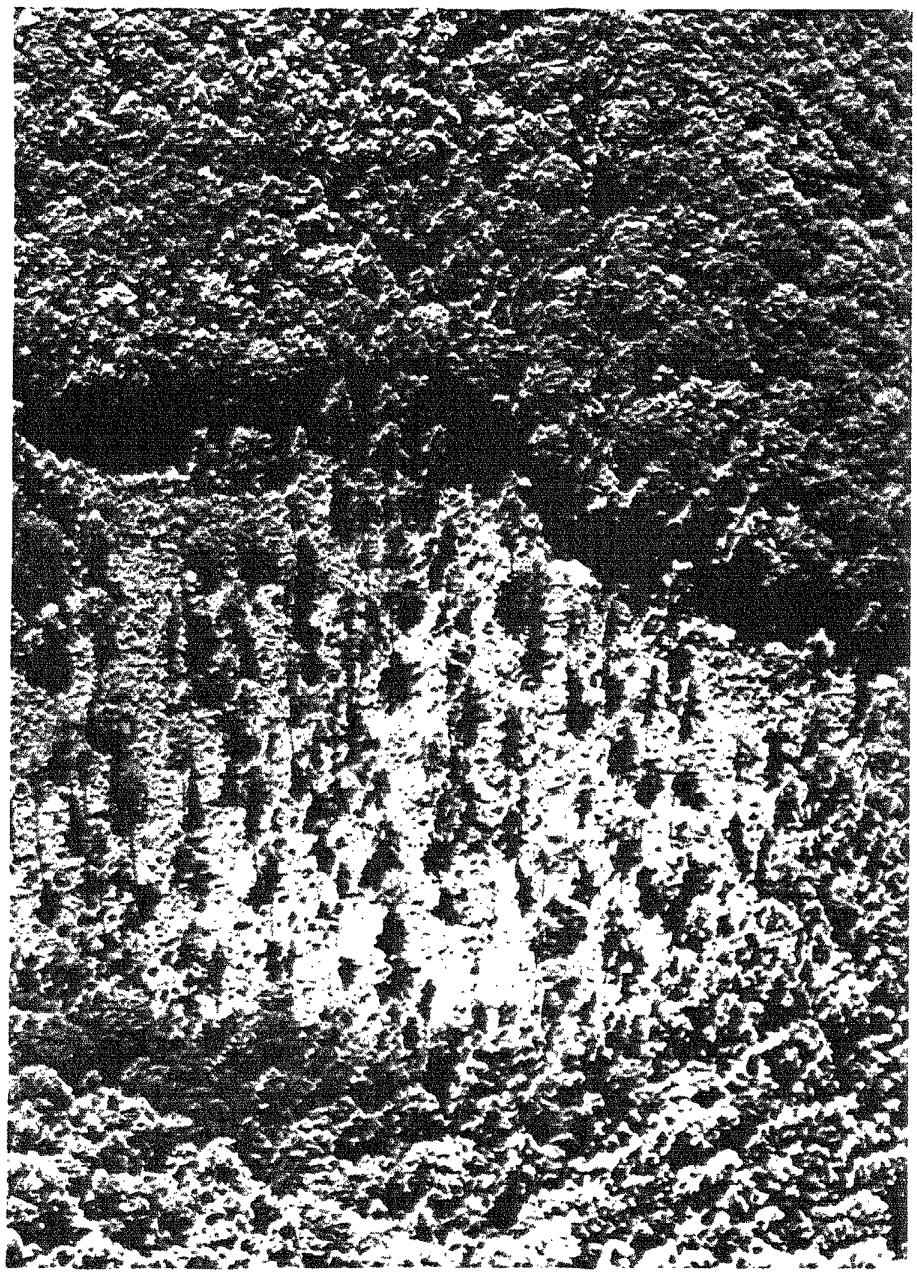

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For attending this conference, each registrant was eligible for 12 hours of Continuing Forestry Education (CFE) credit offered by the Society of American Foresters.

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ACKNOWLEDGMENTS

The editors would like to acknowledge and thank all of the people who served as manuscript reviewers for the Proceedings. The quality of the Proceedings has been improved due to your efforts. We would like to thank Becky Rosenberger for her assistance in typing the program, preparation of the table of contents, typing abstracts, proofreading, and in managing the manuscripts, reviews, and letters associated with the Proceedings. We thank Gary Miller for providing the cover photograph.

Cover Photo: This 1984 aerial photograph was taken from a helicopter three years after deferment cutting in 80-year-old central Appalachian hardwoods on the Fernow Experimental Forest near Parsons, West Virginia. (Photo by James N. Kochenderfer, USDA Forest Service.)

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Edited by

Kurt W. Gottschalk and Sandra L. C. Fosbroke

SPONSORED BY:

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FOREWORD

This conference is the tenth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, University of Tennessee, Southern Illinois University with the North Central Forest Experiment Station (NCFES), Pennsylvania State University with the Northeastern Forest Experiment Station, and Purdue University with NCFES. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the biology and management of central hardwoods by forest scientists from throughout the Central Hardwood Region of the eastern United States. As with previous Proceedings, a wide range of topics that represent the broad array of research programs in this area is represented.

The social and biological characteristics of the Central Hardwood Region make it unique in comparison with other forest regions of the United States. For example, one-fourth of the United States human population resides in this region. Approximately 90% of the land is in private ownership and public lands tend to be small and fragmented with private inholdings. These and related conditions play critical roles in the practice of forestry in this region. The information presented in this Proceedings is important to the long-term management of the forest resources of this unique region.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two (usually three) scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and content of their papers.

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POSTER SESSION

TREE REGENERATION FOLLOWING GROUP SELECTION HARVESTING IN SOUTHERN INDIANA

Dale R. Weigel and George R. Parker[1]

Abstract: An increased interest in the use of group selection harvesting in the Central Hardwood forests has emphasized the lack of scientific information about species response under this uneven-aged management system. Tree regeneration response following group selection harvesting was studied on thirty-six group selection openings on the Naval Surface Warfare Center, Crane Division in southern Indiana. The objectives were to determine whether aspect, age, species group, size of the opening, or their interactions had any influence on the number of stems or average height of the tree regeneration. Two different aspects, three postharvest age classes, and three opening sizes were examined. Yellow-poplar and dogwood were the most abundant stems ≥ 2.5 cm dbh, and dogwood and cherry-ash-walnut were the most abundant stems < 2.5 cm dbh. Stem density (< 2.5 cm dbh) was influenced by age, aspect, and the age/species group and aspect/species group interactions. The north aspect and the oldest openings contained the highest number of stems per hectare for stems < 2.5 cm dbh. Age, species group, and their interaction influenced average height for stems ≥ 2.5 cm dbh.

INTRODUCTION

Recently there has been an increased interest in the use of group selection for the regeneration of Central Hardwood forests. Since the mid 1960s clearcutting was one of the most commonly used methods to regenerate Central Hardwood forests on national forest lands. Its use was encouraged by research completed by Roach and others (1968), and by Sander and Clark (1971). Therefore, research conducted by the USDA Forest Service and other researchers has centered around the use of clearcutting with limited research effort given to uneven-aged management.

The renewed emphasis in uneven-aged management has underscored the need for information on uneven-aged silvicultural systems. There is little scientific information about Central Hardwood regeneration under uneven-aged management which addresses the effect of opening size, parent stand composition, variation within an opening, temporal change, or aspect on regeneration.

The group selection method was developed to combine the benefits of single-tree selection and even-aged management (Marquis 1978). A benefit of single-tree management is the retention of a fairly continuous canopy providing a more natural appearing forest stand. Even-aged management provides for the regeneration of shade intolerant tree species. Thus, group selection should provide for the regeneration of intolerant and intermediate trees while retaining a mostly continuous forest canopy.

The suggested size of the group opening varies from the removal of a few trees to many trees. There has been much discussion on the maximum and minimum size. Marquis (1989) suggests an opening of a tenth to a quarter acre in size with a maximum of a half acre. An opening from a half acre to one acre in size is recommended to regenerate intolerant species (Law and Lorimer 1989, Sander and Clark 1971). Openings of up to two acres have been mentioned as group selection (Mills and others 1987) but if the openings are larger than an acre Marquis (1989) and Marquis and Johnson (1989) suggest they be termed patch clearcuts.

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Light reaching the group selection openings can be managed (Fischer 1981) by controlling the shape and placement of the opening on the landscape. Thus, the regeneration of intolerant species can be encouraged by the proper shape and location of the group selection openings.

This paper will report how the quantity and height of the four most prevalent species groups; oak-hickory, yellow-poplar, dogwood, and beech-sugar maple, are influenced by the age, size, and aspect of the group selection openings.

METHODS

This research was conducted on the Naval Surface Warfare Center-Crane Division, (NSWC), located in south central Indiana. NSWC contains over 62,000 acres of which more than 48,000 are forested. Uneven-aged management has been the regeneration system used at NSWC since timber management began there in the early 1960s.

Nearly the entire NSWC is unglaciated and lies within the Crawford Upland Section of the Shawnee Hills Natural Region as described by Homoya and others (1985). It is characterized by rugged hills with sandstone cliffs and rockhouses. The forest vegetation consists of oak-hickory on the upper slopes with a mesic component in the coves and bottoms. Soils in the study area were of the Wellston association characterized as deep and moderately deep, gently sloping to very steep, well drained soils formed in loess and material weathered from sandstone, siltstone, and shale on uplands (USDA Soil Conservation Service 1988). The group selection openings ranged in elevation from 170 m to 260 m.

The overstory composition surrounding nineteen of the group selection openings was classified as oak-hickory by the NSWC stand inventories. The oak-hickory stands averaged 75% oak-hickory while no other species group contributed over 10%. Seventeen of the group selection openings were surrounded by stands of mixed hardwood. The mixed hardwood stands contained 44% oak-hickory, 21% beech-sugar maple, 11% yellow-poplar, and no other species group contributing more than 10%.

All timber sale contracts from NSWC for the period 1971 to 1985 were examined for potential group selection sample sites. The group selection harvests were then divided into three age classes depending on the time of harvest: 6-10 years from harvest (1981-1985), 11-15 years from harvest (1976-1980), and 16-20 years from harvest (1971-1975). After year 20, timber stand improvement work was begun on these stands thus influencing the composition of the groups. Stands harvested less than 6 years ago were not examined because the group openings were still changing rapidly and species dominance had generally not become well established.

Each timber sale area was located on aerial photos and examined stereoscopically to locate as many group selection openings as possible. Group openings in bottomlands or on ridge tops were not sampled. The openings were divided into groups of north and south aspect, using the aerial photos and topographic maps. The divisions, north aspect 315°-135° and south aspect 136°-314°, were based on previous work in southern Indiana by Hannah (1968) and by Van Kley (1993). Once all timber sale contracts were examined, six openings from each of the three age classes for each of the two aspects were randomly selected from the pool of openings for sampling. Thus, there were 12 openings per age class or 18 openings per aspect for a total of 36 openings.

All selected openings were examined in the field to verify: (1) that the aspect was appropriately identified, (2) that the opening was fairly distinct and discernible, (3) that the surrounding stand was mature upland central hardwoods, and (4) that the opening was not in an area of reverting field. Each group opening failing to meet conditions (2) through (4) was dropped, and a new one was randomly selected.

Woody plant species were sampled on transects extending from the center to the edge of each opening. One-meter-wide transects were used for stems less than 2.5 cm diameter at breast height (dbh, 1.37 m above ground), and 2-meter-wide transects were used for all stems greater than or equal to 2.5 cm dbh. Transects extended upslope, downslope, and in both directions across the slope, beginning 1 meter from the center of the opening and ending at the edge of the opening as defined by the trunks of the mature trees surrounding the opening. The ending of transects at the base of the trees bordering the opening follows Runkle's (1982) method of measuring extended canopy gaps. Each transect was subdivided into 1-meter lengths for sampling woody species by location along the transect. Field data collection was completed during the summer of 1991.

Height (in 25-cm categories) and distance from the plot center (in 1-m increments) were measured by species for each stem less than 2.5 cm dbh. Dbh (to the nearest 0.1 cm), height (nearest 1 m), crown class (in relationship to the regeneration), and distance from the plot center (1 m) were recorded by species for woody stems greater than or equal to 2.5 cm dbh.

Aspect was determined in the field, and area of each opening was calculated using the length of each transect to determine the area of an ellipse. The group openings ranged in size from .07 ha to .23 ha with an average size of .12 ha. For analysis the openings were divided into three size classes; less than 0.1 ha with 12 openings, 0.1 ha to 0.14 ha with 15 openings, and greater than 0.14 ha with 9 openings. Also for analysis, the species were put into the following eight groups: (1) oak-hickory, (2) yellow-poplar, (3) dogwood, (4) beech-sugar maple, (5) shrubs and small trees, (6) cherry-ash-walnut, (7) sassafras, and (8) miscellaneous species. Only the first four species groups are discussed in this paper.

Analysis of variance was used to determine whether the variables aspect, age, size of opening, species group, or their interaction had any effect on the average number of stems per hectare or average height. When an effect was found to be significant, the Student-Newman-Keuls multiple range test was used to determine differences between the means.

RESULTS

Number Of Trees

DBH ≥ 2.5 cm. Species group was the only variable which influenced the number of stems per hectare ≥ 2.5 cm dbh. Aspect, size of the opening, and age had no influence. Yellow-poplar was the most abundant species group, followed by dogwood, beech-maple, and finally oak-hickory. This ranking was consistent for all age classes, group opening size classes, and both aspects (Figure 1a-c). While this ranking was constant, it was seldom significant. Yellow-poplar was significantly more abundant than beech-maple and oak-hickory in the 11-15 year age class. Abundance was not significantly different among species groups for the youngest and oldest openings. Beech-maple was the only group to show a significant change in number of stems between age classes. The oldest age class contained significantly more stems than the two youngest age classes.

There was no significant difference between individual species groups among opening sizes or aspects. Yellow-poplar and dogwood were significantly more abundant than beech-maple and oak-hickory in the smallest openings and yellow-poplar was significantly more abundant than beech-maple and oak-hickory in the middle size openings (Figure 1b). In the largest openings there was no significant difference between species groups.

Yellow-poplar was significantly more abundant than oak-hickory on the north aspect (Figure 1c). There were significantly more yellow-poplar and dogwood than oak-hickory, and significantly more yellow-poplar than beech-maple in openings with a southern aspect.

DBH < 2.5 cm. The number of smaller stems, < 2.5 cm dbh, was influenced by the age, aspect of the openings, and by the species groups. The size of the openings did not influence the number of stems. The two oldest age openings had more stems than the youngest. In the youngest openings, there were significantly more dogwood stems than the other three species groups (Figure 2). In the middle age openings, there were significantly more dogwood stems than yellow-poplar. In the oldest openings sampled, there were significantly more dogwood and beech-maple than oak-hickory and yellow-poplar.

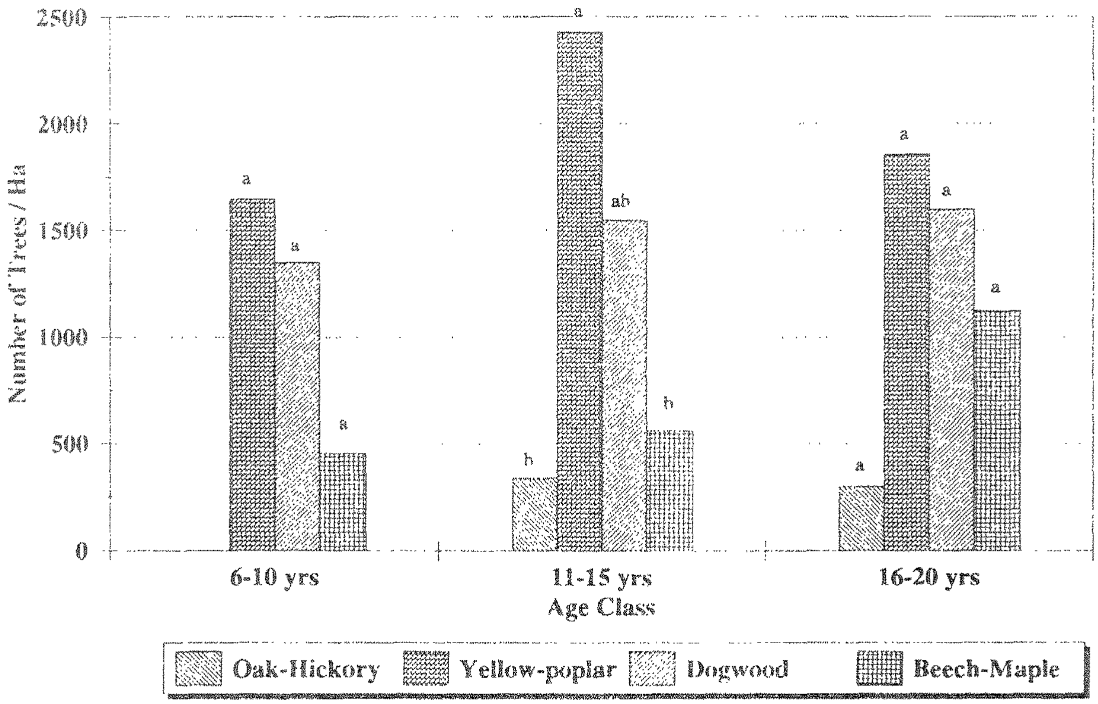

Figure 1a. Number of trees greater than or equal to 2.5 cm dbh by species group and age class. Species groups within an age class with the same letter are not significantly different at the 0.05 level.

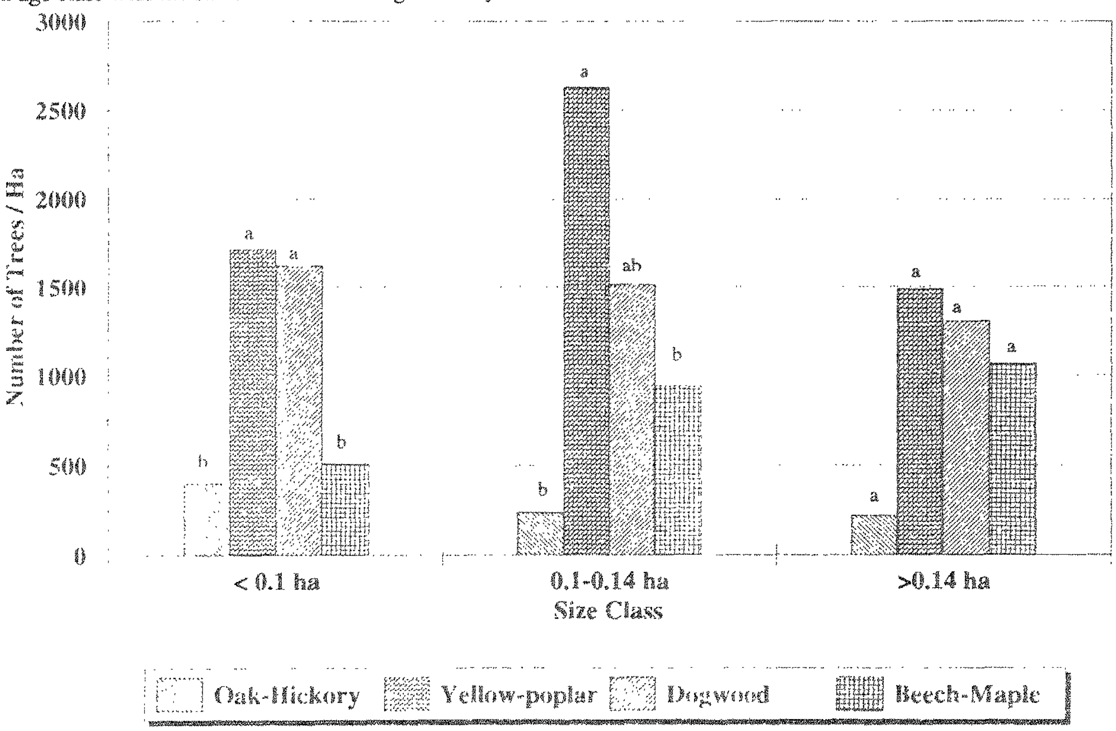

Figure 1b. Number of trees greater than or equal to 2.5 cm dbh by species group and size class. Species groups within a size class with the same letter are not significantly different at the 0.05 level.

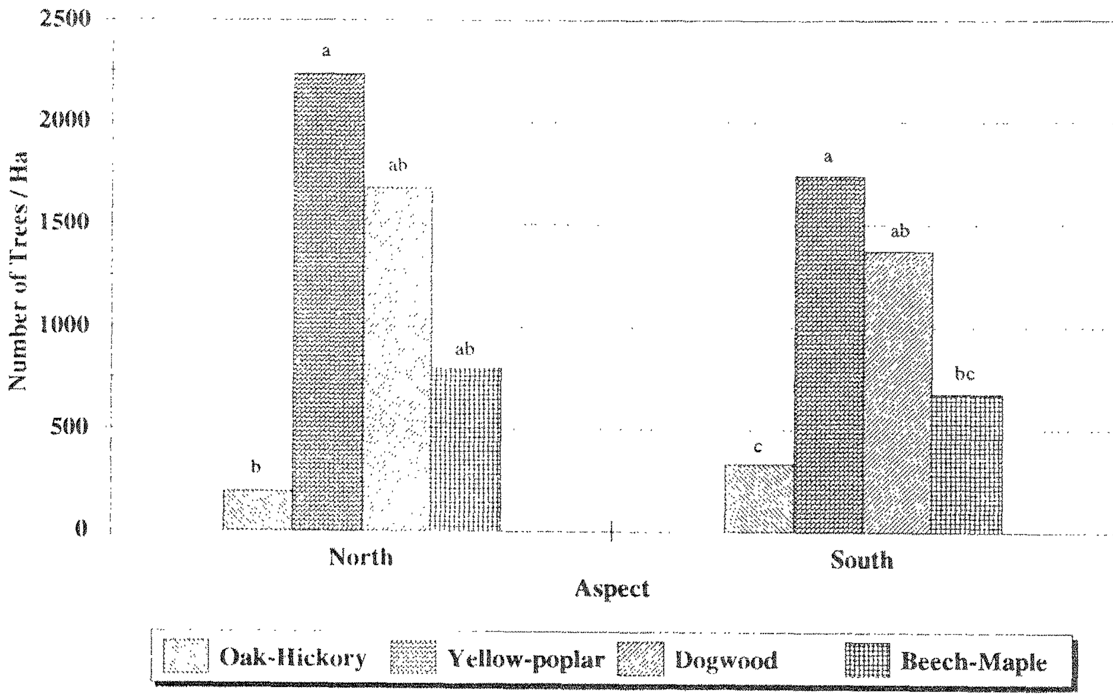

Figure 1c. Number of stems greater than or equal to 2.5 cm dbh by species group and aspect. Species groups within each aspect with the same letter are not significantly different at the 0.05 level.

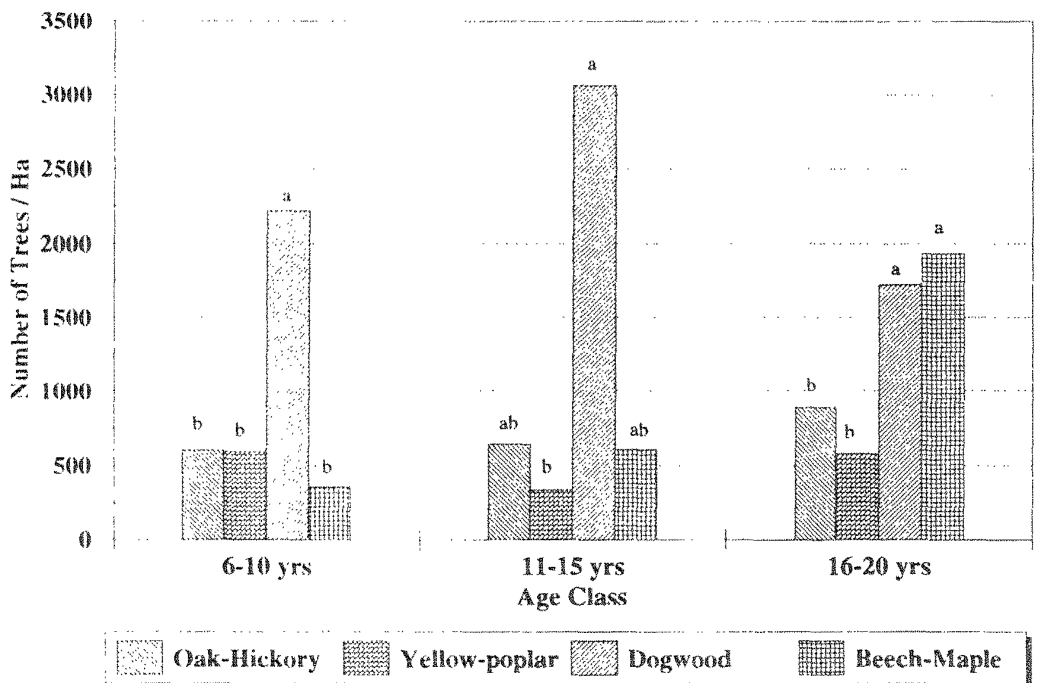

Figure 2. Number of trees less than 2.5 cm dbh by species group and age class. Species groups within an age class with the same letter are not significantly different at the 0.05 level.

Average Height

DBH ≥ 2.5 cm. Height of stems ≥ 2.5 cm dbh was significantly influenced by age of the opening and species groups, but not by size or aspect of the opening. Yellow-poplar was the only species group to show a significant increase in height between age classes. Beech-maple and dogwood showed a slight decrease in height from the middle to the oldest age class. Oak-hickory showed a nonsignificant increase in height from the youngest to the oldest openings.

In the youngest age class, beech-maple, dogwood, and yellow-poplar were significantly taller than oak-hickory; also, beech-maple was significantly taller than dogwood (Figure 3a). Beech-maple and yellow-poplar were significantly taller than the other two species groups in the middle age class. By the oldest age class, yellow-poplar was significantly taller than the other groups with beech-maple and oak-hickory significantly taller than dogwood.

Yellow-poplar and beech-maple showed a positive height increase with increasing opening size (Figure 3b). However, only the increase from the middle size openings to the largest openings was significant for yellow-poplar. Oak-hickory and dogwood showed a negative response to increased opening size. Yellow-poplar and beech-maple were significantly taller than oak-hickory and dogwood only in the largest openings.

DBH < 2.5 cm. Stems < 2.5 cm dbh decreased in height from youngest to oldest stands. This trend was significant. The other significant variable was species group. Neither aspect nor size of opening had a significant affect on the average height of the regeneration. This decrease in height was most likely due to the taller stems growing into the larger size class and to mortality.

Yellow-poplar was significantly taller than the other species groups for the two youngest age classes but by the oldest age class it was the shortest (Figure 4). Dogwood remained the only group taller than 1 meter, by the oldest age class.

DISCUSSION

The oak-hickory type is the most widespread and currently covers the greatest area in the Central Hardwood forests (Sander and Fischer 1989). The perpetuation of this type is of great concern to many people. In this study area the parent stands were dominated by the oak-hickory group. As indicated by trees ≥ 2.5 cm dbh, the future stands will not be dominated by the oak-hickory group which contained the fewest number of stems. It would appear that the future stand will be comprised of a diversity of species with yellow-poplar being the most dominant. The stems < 2.5 cm dbh confirm this trend with the oak-hickory group not among the most common.

These results differed from those reported by Runkle (1981) and Barden (1981), who reported that species replaced themselves in larger canopy gaps. However, their research was conducted in forest stands where tolerant species dominated the forest canopy and tolerant species replaced tolerant species. In stands with less tolerant oak-hickory overstories, Standiford and Fischer (1980) reported a decrease from 80% oak before harvest to 7% oak 12 to 15 years after harvest. Fischer (1987) and George and Fischer (1991) showed a similar trend for clearcuts on the Hoosier National Forest. They found that the oak-hickory group declined in numbers from the original parent stand.

One unknown in the study was the quantity and type of advanced regeneration present before harvest. Many of the group selection openings studied might have been located in areas that contained little advance regeneration, accounting for the low percentage of oak-hickory. Sander (1978) and Sander and others (1983) suggested that successful oak regeneration following harvest depends primarily on the amount and size of oak present as advance regeneration prior to harvest.

If oak advance regeneration is not present in sufficient quantities, steps must be taken to increase the quantity. Loftis (1985, 1988) recommended the use of herbicide to remove undesirable stems, allowing for the increase in size and number of desirable stems. Johnson and others (1986) suggested, in conjunction with a shelterwood silvicultural system, the planting of oak seedlings 3 years before harvest to increase the number of oaks.

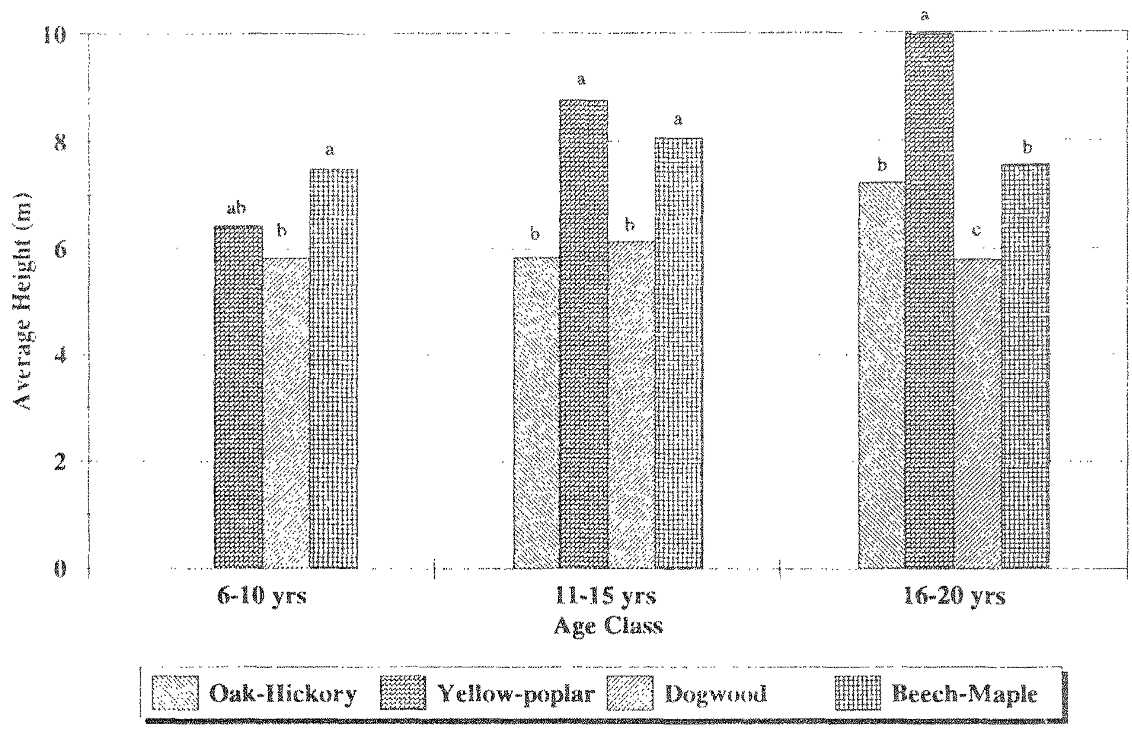

Figure 3a. Average height of trees greater than or equal to 2.5 cm dbh by species group and age class. Species groups within an age class with the same letter are not significantly different at the 0.05 level.

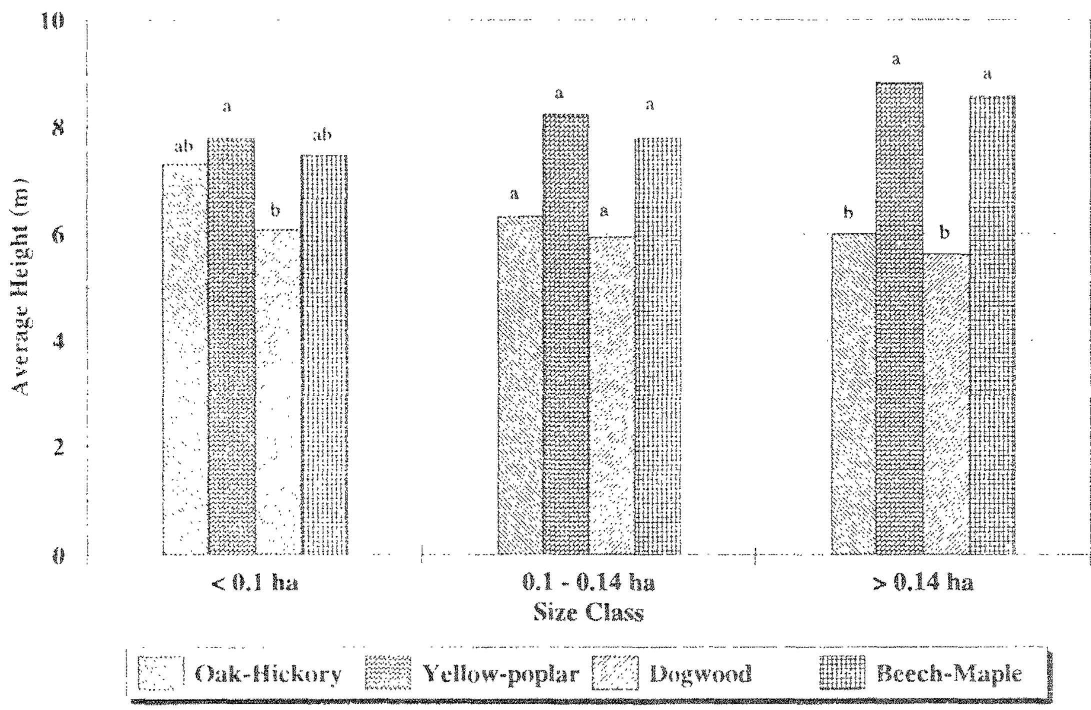

Figure 3b. Average height of trees greater than or equal to 2.5 cm dbh by species group and size class. Species groups within a size class with the same letter are not significantly different at the 0.05 level.

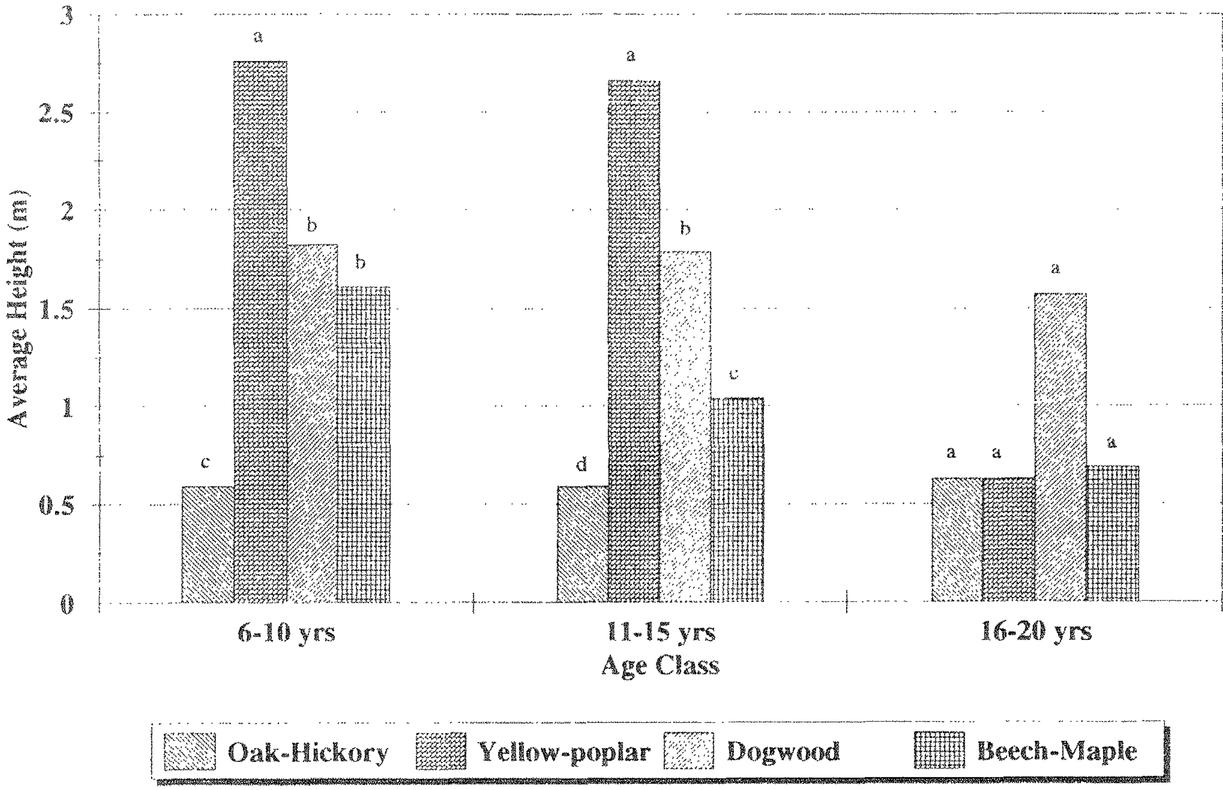

Figure 4. Average height of trees less than 2.5 cm dbh by species group and age class. Species groups within an age class with the same letter are not significantly different at the 0.05 level.

As applied, the group selection openings gave no evidence of promoting oak regeneration success. Additional investigation to monitor group selection openings with known levels of advance oak reproduction would be beneficial.

CONCLUSION

This study was an initial examination of tree regeneration following group selection harvesting in openings of three age classes. The progression of tree regeneration through time was not directly examined in this study; it was inferred from an examination of thirty-six group selection openings observed at different times since harvest. Whether or not the regeneration in the youngest group selection openings will contain the same mix of tree regeneration as the oldest group selection openings in another decade cannot be known with certainty, but it seems a likely course of development.

A better study could be conducted if it were established prior to harvesting. This would allow for the measurement of the advanced regeneration and the overstory composition. The regeneration within the openings could then be followed over time to obtain a more accurate picture of the progression of tree regeneration. Establishing the study prior to harvest would also permit the control of opening size, shape, and placement. Unfortunately this was not possible for this study.

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REGENERATION IN DEFOLIATED AND THINNED HARDWOOD STANDS OF NORTH-CENTRAL WEST VIRGINIA

R.M. Muzika and M.J. Twery[1]

Abstract: Overstory species regeneration was examined in 1989, prior to gypsy moth defoliation and thinnings, on 16 stands in the West Virginia University Forest. Three stands were thinned and defoliated while five were thinned only and three were defoliated only. Five stands were neither thinned nor defoliated. Data were collected from these stands for three years subsequent to the disturbances. The general response to defoliation was similar in number of seedlings irrespective of thinning, i.e., there was an initial depression of regeneration, although it was more noticeable in stands that were not thinned. Total seedling production increased significantly on thinned stands two years following thinning, but differences disappeared by third year after treatment. For both defoliated and undefoliated stands, any effect of thinning on total seedling abundance was lost by 1992. Oak regeneration was greatest on control stands and stands that were thinned but not defoliated. Defoliation alone was detrimental to oak regeneration, while thinning moderated the defoliation effect. Red maple seedlings dominated numerically, but black cherry was the most abundant species in the larger size classes in all stands irrespective of treatment, and is likely to dominate the next generation of overstory trees in this area.

INTRODUCTION

A relatively thorough literature exists explaining the effects of gypsy moth defoliation on overstory species composition (Campbell and Sloan 1977, Feicht and others 1993, Herrick and Gansner 1988, Stephens and Hill 1971, Twery 1990, among others). Less is known, however, about understory vegetation and woody species regeneration responses to gypsy moth defoliation. Such knowledge is critical in predicting species replacement and determining appropriate management techniques for post defoliated stands as well as in advance of defoliation.

As silvicultural methods are employed with greater frequency in attempts to reduce susceptibility and vulnerability to gypsy moth (Gottschalk 1993), the understory responses to such treatments should be an important consideration. In many ways, defoliation resembles thinning and as such is likely to produce comparable effects, particularly in creating canopy openings, and increasing light penetration. In areas that have been thinned and defoliated, the potential for dramatic changes in species composition is great. With this study, we examine the effects of both defoliation and thinning on woody species regeneration.

Oaks (*Quercus* spp.) represent the most favored host of gypsy moth. Declining oak dominance from the potential of extreme oak mortality is exacerbated by oak regeneration problems which appear to be common throughout Eastern forests (Loftis and McGee 1993). Competition from intolerant and intermediate species contribute to regeneration problems. For example, red maple (*Acer rubrum* L.) is one of the more abundant regenerating species in many oak-dominated forests in the Midwest (Host and others 1987, Johnson 1992) and the Northeast (Lorimer 1984). In the Ridge and Valley Province in Pennsylvania, Nowacki and Abrams (1992) found that maple, cherry (*Prunus*), and/or birch (*Betula*) are slowly replacing oak and that maple and beech (*Fagus grandifolia* Ehrh.) are dominating historically white oak (*Quercus alba* L.) dominated areas. Studies by Allen and Bowersox (1989), Ehrenfeld (1980), Fosbroke and others (1991), and Hix and others (1991) have examined regeneration following gypsy moth

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defoliation. Results of the previous research consistently indicate a reduced regeneration of previously dominant overstory species.

This study examines woody species regeneration, particularly focusing on oak, in mixed hardwood stands of the central Appalachians. Specifically, the study assesses the impact of silvicultural techniques used to minimize gypsy moth defoliation damage in addition to the effect of gypsy moth defoliation and mortality on woody regeneration.

METHODS

The study area is the West Virginia University Forest in north central West Virginia. The forest is located in Preston and Monongalia Counties, within the general boundaries of the mixed mesophytic forest region (*sensu* Braun 1950) in the slightly folded region of the Appalachian Plateau. The forest is generally considered a mixed hardwood forest, although is purported to have been heavily dominated by white oak at one time (Carvell and others 1978). Elevation of the study area ranges from 1800 to approximately 2300 feet, and Dekalb series represent the most abundant soil type.

Since the late 18th century the area has been heavily disturbed. Charcoal manufacture for the iron industry accounted for early use of the timber resource, followed by specialty wood products such as railroad ties and whiskey barrels. Nearly all of the Forest was eventually clearcut and much of it burned by the early 1930's (Carvell and others 1978).

For the current study, sixteen stands (eight pairs), ranging from 19.3 to 31.2 acres and accounting for a total of 408 acres were selected in 1989. A pair represents two adjacent stands of similar species composition and size structure, and reflects comparable suitability as host for the gypsy moth. One of each pair (hereafter referred to as "stands"), was thinned in Fall, 1989 or early Spring 1990. The objective of thinning was to reduce stand susceptibility or vulnerability (Gottschalk 1993) prior to potential gypsy moth defoliation. Defoliation followed in six stands in 1990 and in 1991. Each of the six stands incurred over 50% defoliation of preferred (Twery 1990) species and over 40% defoliation of all species for two years. Defoliation on the other stands, i.e. background defoliation level, was less than 15% of all species, including preferred. Using the random (defoliation) and fixed (thinning) treatments, the stands were classified as **C** (control), unthinned and undefoliated, **T** - thinned and undefoliated, **D** - defoliated but unthinned, and **DT** - defoliated and thinned. The **C** and **T** groupings are paired, and the **D** and **DT** groups are paired, e.g. **C1** and **T1** represent one pair of stands, as do **D1** and **DT1**.

Species composition in all structural layers was determined in 1989 prior to any treatment, and was remeasured in 1990, 1991, and 1992. Nomenclature follows Little (1979). Twenty 0.1 acre (0.04 ha) plots were established for overstory sampling and within each of these plots three, systematically located, 113 ft^2 (10.5 m) circular plots were sampled for woody seedling regeneration. Regeneration in the control stands (**C**), however, was not measured in 1990. Species were identified and categorized by the following size classification:

Size class 1:	all woody plants to 1 ft tall
Size class 2	1 to 5 ft tall
Size class 3	Greater than 5 ft tall, but less than 2.49 inches dbh
Overstory	Greater than 2.49 inches dbh

We used repeated measures analysis of variance to determine temporal trends in regeneration and to examine treatment effects. The data from 1989 were used as contrasts to determine significance over time. Analysis of covariance, using the pre-treatment data as covariates, was used to examine individual treatment effects.

RESULTS

Overstory Species Composition

Generally a mixed hardwood forest with a substantial component of oak, the basal area of much of the West Virginia University Forest was dominated by yellow-poplar (*Liriodendron tulipifera* L.) in 1989 (Table 1). In stands dominated by oak there were fewer overstory species overall compared to stands dominated by yellow- poplar. Although considered the dominant species in the West Virginia University Forest at one time, white oak accounted for only a small proportion of total basal area on all stands. The red maple component ranged from 4 to 17% of total stand basal area initially.

Significant decreases in overstory basal area occurred in all but the control stands (Table 1). Although stand basal areas were reduced substantially in the thinned stands, the relative contribution of the important overstory species remained somewhat constant. One of the objectives of the thinning was to reduce the overstory oak component, but this proved difficult in practice because of the actual distribution of trees. In **D** and **DT** stands, red maple proportion in the overstory increased to as much as 47% in some stands. Black cherry (*Prunus serotina*) increased substantially on one defoliated stand (**D2**).

Initial Regeneration

Table 2 includes only those species likely to attain overstory size in the 16 stands. Some non-overstory woody species were also plentiful. For example, blueberry (*Vaccinium* spp.) was the third most abundant woody species across all sixteen stands. Maple-leaf viburnum (*Viburnum acerifolium* L.), spicebush (*Lindera benzoin* (L) Blume.), and blueberry accounted for a total of 12% of all individuals sampled. By contrast, red oak (*Quercus rubra* L.), the most abundant oak species, accounted for only 4% of all individuals sampled in 1989. Oak regeneration in general was minimal and was most apparent on those stands with a strong oak component, **D1**, **D2** and **T5**. Red oak regeneration occurs most abundantly in stands with a considerable red oak overstory, but in stands with the greatest oak component in the overstory, the understory was dominated by black cherry (**D2** and **DT2**) and red maple (**D3** and **DT3**). *Vaccinium* also was a major component in the understory in those four stands. Numerically, black cherry and red maple dominated the regeneration overall. Overstory species, present but excluded from the table, due to small numbers include elm (*Ulmus rubra*), beech, black locust (*Robinia pseudoacacia*), basswood (*Tilia americana*), sugar maple (*Acer saccharum*), and American chestnut (*Castanea dentata*).

Effect of Treatments on Total Number of Seedlings

Throughout the four year period, there were slightly more seedlings on the undefoliated than on defoliated stands. Over the four years, number of seedlings on thinned, defoliated stands did not change, but thinning contributed to a significant increase in the total number of seedlings on defoliated stands in 1990 and 1991 when compared with unthinned stands. By 1992, there was no significant difference due to thinning, and seedling abundances for that year were nearly identical for all stand types. The 1992 values were similar to the 1989 values (Fig. 1). On stands that were undefoliated, thinning significantly increased seedlings in 1991, but there was no effect by 1992 (Fig. 2). Thinning did not result in an increase in total number of seedlings; rather, differences arose primarily because of a decrease in seedling numbers in unthinned stands.

Repeated measures analysis of variance indicates no general change in total number of seedlings (all species) from 1989 to 1992; however, there was a significant treatment effect in 1990 ($P<0.001$), and 1991 ($P<0.001$). The treatment effect was lost by 1992. There is a significant treatment by time interaction, suggesting that the pattern is not the same for all treatments.

Table 1. Relative overstory composition of study stands based on stems ≥ 2.5 inches dbh. Basal area represents the total basal area of each stand and the percent each of the major species contributes to total for 1989 (pre-treatment), and for 1992.

Stand	Basal Area (ft^2/ac) year - total	Red oak %	White oak %	Chest-nut oak %	Other oaks* %	Red maple %	Yellow-poplar %	Black cherry %
C1	1989 - 133.4	10.4	1.8	14.5	5.1	8.7	40.5	0.5
	1992 - 137.6	10.9	1.9	13.5	3.1	9.4	39.2	0.6
C2	1989 - 134.3	25.5	3.5	9.3	4.6	16.3	28.1	2.3
	1992 - 140.6	24.0	3.4	9.4	4.7	16.5	28.5	2.3
C3	1989 - 136.0	12.1	5.1	9.5	8.3	8.7	40.6	0.6
	1992 - 140.3	12.4	5.0	9.7	8.4	9.3	41.2	0.4
C4	1989 - 133.5	31.5	3.0	13.3	0.9	16.4	8.0	14.7
	1992 - 142.3	31.3	3.0	13.4	0.8	16.6	8.2	14.8
C5	1989 - 122.6	35.6	1.7	9.1	2.0	16.4	21.7	4.7
	1992 - 127.8	37.5	1.5	9.2	2.0	16.8	22.1	4.4
T1	1989 - 147.5	20.8	2.3	13.3	4.3	12.2	30.8	1.9
	1992 - 107.4	21.2	1.4	7.1	4.9	14.7	36.3	0.6
T2	1989 - 149.0	18.3	1.6	15.6	3.7	13.8	37.2	3.0
	1992 - 114.4	18.3	2.0	10.9	1.6	18.2	41.0	3.9
T3	1989 - 144.1	10.4	0	0.3	1.3	3.9	64.8	2.7
	1992 - 103.0	10.8	0	0.1	1.9	5.5	68.0	1.4
T4	1989 - 132.7	42.3	3.5	5.1	1.4	14.0	7.6	14.4
	1992 - 88.4	47.1	4.0	1.5	0.5	16.9	6.0	11.7
T5	1989 - 125.9	28.8	6.7	13.2	5.9	14.6	22.1	3.2
	1992 - 86.6	32.4	5.1	12.0	3.8	17.5	20.0	3.9
D1	1989 - 110.7	43.8	4.0	5.1	0.1	17.3	8.6	1.5
	1992 - 75.0	22.6	1.5	1.5	0	29.3	14.2	2.8
D2	1989 - 120.5	53.4	5.2	17.0	4.2	6.5	0.6	12.3
	1992 - 49.8	30.5	1.2	15.2	0.7	18.1	0	30.6
D3	1989 - 129.5	51.3	6.4	12.4	5.7	15.7	0.7	1.7
	1992 - 52.6	38.2	0.1	0.5	0	46.1	1.8	4.4
DT1	1989 - 130.8	34.2	1.9	4.0	2.0	12.5	27.0	0.9
	1992 - 84.4	11.4	0	0.3	0	22.0	44.9	1.9
DT2	1989 - 125.7	62.3	3.6	6.6	8.6	7.4	0	9.6
	1992 - 69.1	63.0	0.8	3.1	7.8	14.0	0	9.7
DT3	1989 - 127.8	40.6	11.6	7.9	6.2	16.8	0	0.4
	1992 - 38.0	18.3	0	3.6	0.6	47.4	13.4	1.9

Table 2. Overstory species regeneration prior to treatments. Values represent number of seedlings per acre of each species. All size classes are combined.

Stand	red maple	black cherry	sassa-fras	yellow poplar	red oak	black gum	chest-nut oak	white oak	sweet birch	hick-ory	sour-wood	mag-nolia	ash	black oak	scarlet oak
C1	25167	957	3000	2544	334	546	373	109	129	103	193	39	77	6	6
C2	8982	8725	1818	1298	495	777	135	77	251	19	0	45	13	0	0
C3	12734	6001	8397	1022	771	244	752	964	0	71	283	51	39	39	13
C4	3155	15330	835	874	430	6	84	6	315	13	0	0	6	0	0
C5	6624	13486	1047	3347	1092	141	180	141	77	32	0	0	308	0	0
T1	13730	1561	2339	777	655	996	668	173	180	244	148	26	6	6	0
T2	8886	8956	1144	2634	482	315	238	77	45	0	0	6	6	6	0
T3	1606	3225	5872	3540	437	6	13	13	45	64	0	6	0	39	0
T4	3553	12092	398	970	578	0	64	186	302	13	0	0	0	13	0
T5	7408	9278	1471	4446	1632	77	116	116	0	77	0	411	0	13	0
D1	13171	411	341	732	1574	167	64	90	39	13	0	0	0	6	0
D2	4106	14116	463	26	1375	6	353	58	51	0	0	0	0	32	0
D3	6772	617	141	6	1092	720	334	109	199	0	26	0	0	13	6
DT1	9638	263	1092	2872	1812	443	71	0	418	13	0	0	0	0	0
DT2	3386	11944	328	0	2050	13	135	334	32	45	0	0	0	19	0
DT3	7993	649	1439	0	572	58	32	206	334	0	0	0	0	0	13

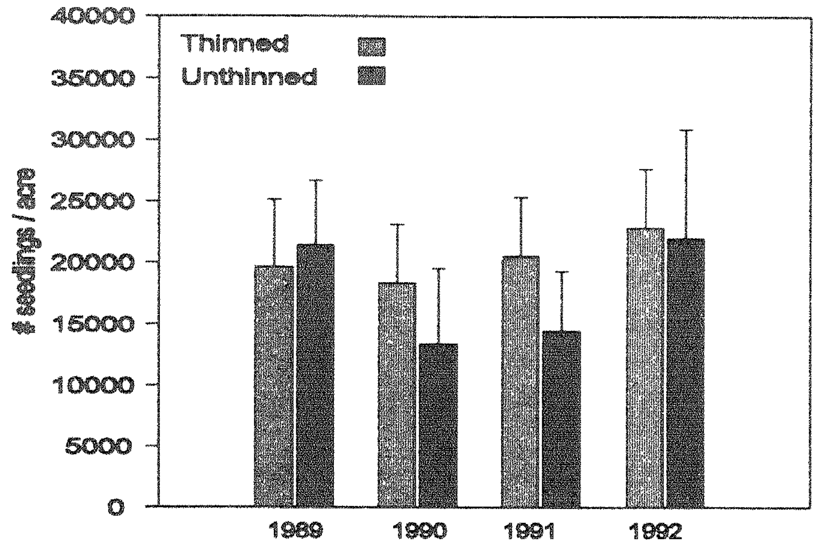

Figure 1. Average seedling abundance (all species) in defoliated stands.

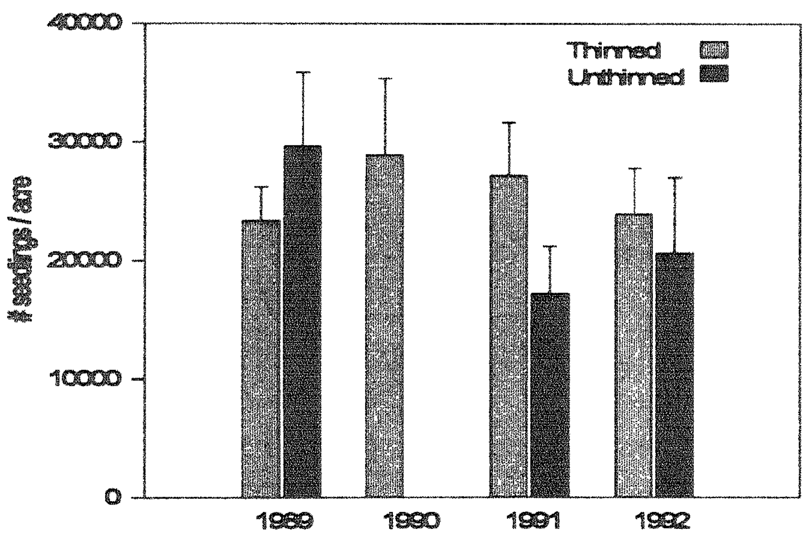

Figure 2. Average seedling abundance (all species) in undefoliated stands. Data were not collected for unthinned stands in 1990.

Oak Regeneration

The number of oak seedlings on defoliated stands (both **D** and **DT**) diminished over time (Figure 3). The decrease was greatest between 1989 and 1990 on **DT** stands; **D** stands dropped further, but after another year. Oak seedling abundance increased in both **T** and **C** stands, although, thinning increased production of oak seedling to a slightly greater extent. With time, in defoliated stands, irrespective of thinning, oak contributed less in successive years, as a consequence of both fewer oak seedlings and an increase in non-oak reproduction. This was confirmed through a significant time effect ($P<0.0001$), and a significant time by treatment effect ($P<0.001$) , but no significant treatment effect ($P=0.21$).

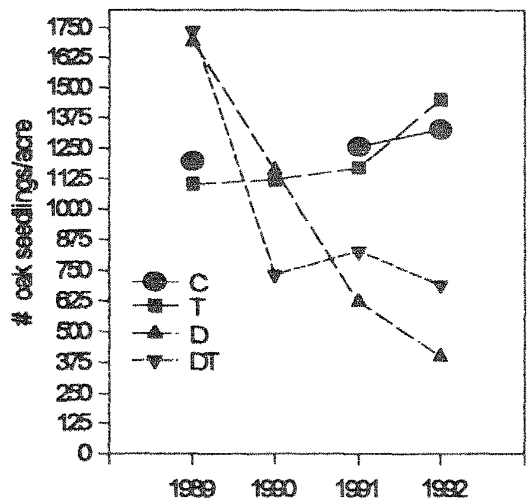

Figure 3. Oak regeneration from 1989 to 1992 for each treatment type. Regeneration was not sampled for control stands in 1990.

Treatment effects are not always consistent when individual stands are examined, and even control stands exhibit wide variation in production of oak seedlings. Figure 4 illustrates the change in oak seedlings as a percentage of original number (1989) of oak seedlings in each stand. With the exception of one stand (**T5**), thinning alone enhanced oak seedling production. Generally, thinning increased oak seedling production relative to no treatment in undefoliated stands, but one pair (**C1**, **T1**) did not follow the pattern of the other undefoliated stands. Defoliation, and thinning in conjunction with defoliation clearly reduced the oak component in the understory. Unthinned defoliated stands lost slightly more oak seedlings than **DT** stands in terms of absolute numbers and relative percentage of 1989 seedling numbers.

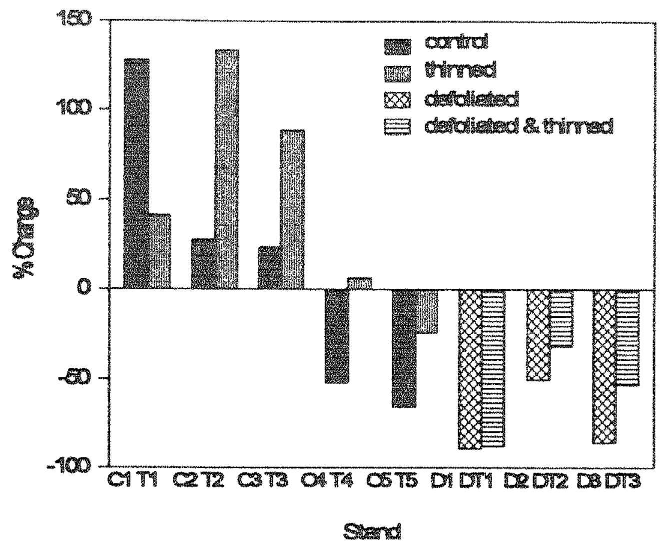

Figure 4. Percent change in oak seedlings from 1989 to 1992 for each stand. Values represent the number of oak seedlings in 1992 as a percentage of 1989 oak seedlings.

In all but one of the defoliated stands the amount that oak contributed to the regeneration decreased each year (Table 3). Pre-treatment (1989) regeneration values were not always comparable in the paired stands, and in no case was oak regeneration a very dominant group among seedlings despite the fact that some of these stands had over 70% basal area in oak originally. Oak contribution to regeneration was greatest prior to disturbance and immediately following initial disturbance (Table 3).

Regeneration Species Composition

Individual species responded differentially to the treatments (Table 4.) Over the four year period, red maple's contribution to total seedlings decreased under all treatments. With thinning alone this decrease was most dramatic. Black cherry increased only slightly in the control stands, but decreased both in raw numbers and as a percent of total seedlings in the other three treatments. Sassafras (*Sassafras albidum*), sweet birch (*Betula lenta*), and yellow-poplar increased in all treatments, but thinning, regardless of defoliation, increased sassafras and sweet birch production dramatically. Red oak increased as a proportion of total seedlings and in actual total number of seedlings in both **T** and **C** stands, while white oak decreased. In both types of defoliated stands, red and white oak diminished over the four years. Other increases in oak species were from 37 to 56 seedlings in **DT** stands for chestnut oak and from 171 to 223 in **T** stands; however, this only represents increases of 0.1%, and 0.3% of all seedlings, respectively . In **C** stands, chestnut oak increased by 1.1%.

Non-overstory woody species can account for considerable competition for regenerating species (Table 4). Of particular note is the abundance of *Vaccinium* spp. (blueberry) in defoliated stands. The presence of this species is not a function of disturbance as much as a reflection of site characteristics. Nonetheless, blueberry abundance is likely deleterious for regeneration, and it appears that thinning helps to reduce blueberry when compared to non-thinned defoliated stands.

Table 3. Oak reproduction in all stands. Each value represents the percentage of oak contribution to total regeneration. Total regeneration includes all species, irrespective of potential to exist in the overstory.

	1989	1990	1991	1992
Stand	%	%	%	%
DT - 1	10.4	1.8	1.1	0.9
D - 1	10.0	4.2	2.4	1.5
DT - 2	9.8	11.7	11.0	10.0
D - 2	6.6	5.9	5.4	3.9
DT - 3	5.4	3.6	1.2	1.5
D - 3	8.1	5.7	4.1	0.7
C-1	2.2	*	7.6	8.4
T-1	6.0	3.8	5.9	7.3
C-2	2.9	*	6.6	5.0
T-2	3.2	4.8	4.6	7.9
C-3	7.7	*	12.7	10.1
T-3	2.3	1.6	2.8	3.8
C-4	2.2	*	2.8	1.5
T-4	4.3	6.0	4.3	4.8
C-5	4.8	*	4.0	3.3
T-5	7.2	4.5	4.3	6.2

* - no data collected for control stands in 1990

Table 4. Percentage of total individuals represented by selected species for 1989 and 1992, by treatment.

	CONTROL		THINNED		DEFOLIATED		DEFOL. & THIN.	
species	1989	1992	1989	1992	1989	1992	1989	1992
red maple	38.2	27.2	30.1	17.8	37.4	35.6	35.7	28.2
black cherry	30.0	31.7	30.0	19.8	23.6	11.9	21.8	10.9
sassafras	10.2	12.1	9.6	22.2	1.5	5.4	4.8	21.7
yellow-poplar	6.1	9.0	10.6	16.4	1.2	5.8	4.9	11.7
red oak	2.1	3.2	3.2	3.9	6.3	1.5	7.5	2.7
sweet birch	0.5	4.7	0.5	6.2	0.5	2.9	1.3	8.9
white oak	0.9	0.9	0.5	0.5	0.4	0.1	0.9	0.1
scarlet oak	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
chestnut oak	1.0	2.1	0.9	1.2	1.2	0.4	0.4	0.5
black oak	0.0	0.2	0.1	0.1	0.1	0.0	0.0	0.1
blueberry	1.2	1.3	1.9	1.3	25.2	32.8	19.3	12.8
black gum	1.2	1.1	1.2	0.6	1.4	1.7	0.9	0.7
viburnum	4.2	2.8	3.8	1.8	0.0	0.0	0.0	0.0
spicebush	0.4	0.8	3.5	4.2	0.4	0.8	0.6	0.6

Effects of Defoliation and Thinning on Size Structure

For those seedlings most likely to reach the overstory, i.e. size class three, treatments had little effect over the four year period (Table 5). Red oak recruitment into the larger size classes was only significant in the thinned stands, with a total of 273 moving into size class 2, a group that had only 33 individuals four years previous. First year seedlings of chestnut oak (*Quercus prinus*) increased in **C**, **T** and **DT** stands. Black and scarlet oak (*Quercus velutina* and *Q. coccinea*) also increased in 1992 in the size classes under five-feet tall in undefoliated stands. White oak showed the poorest response among the oaks.

Certain species responded in a manner characteristic of their early successional nature. Black cherry increased in most size classes everywhere but **C** stands. Sweet birch increased in size class one in all treatment types, and in size class two, everywhere but **C** stands. Yellow-poplar followed a similar pattern, but growth of this species was evident only in **T** and **DT**. Sassafras increased in size classes under five feet in all but the **C** stands also. Thinning treatments (**T** and **DT**) appear to accelerate sassafras growth dramatically, giving rise to an abundance in the 1-5 ft size class during in the four year period.

DISCUSSION

Among studies examining regeneration as affected by gypsy moth defoliation, Allen and Bowersox (1989) sampled forests in both the Allegheny Mts. and Ridge and Valley provinces. The most abundant woody regeneration in many stands in both areas was red maple, accounting for up to 90% of all commercial regeneration in the Allegheny Mountains and 49% in the Ridge and Valley provinces. Birch was a major constituent of regeneration in the Ridge and Valley. The values for red maple in studies by Allen and Bowersox (1989), and Hix and others (1991) surpassed the quantities found at the West Virginia University Forest. Stands on the West Virginia University Forest exhibit greater species richness in regeneration than the previously mentioned studies, for black cherry and yellow poplar were commonly found, in addition to sweet birch and red mapels. Yellow-poplar seedlings ranged from 1259 (**D**) to 2585 (**DT**) seedling/acre at the West Virginia University Forest, while they were not even noteworthy in the previous work. Also, black cherry seedlings surpassed all but red maple in our study and were not noted by Allen and Bowersox (1989). Hix and others (1991) found 2333 black cherry seedlings/acre, a value comparable to the number found at the West Virginia University Forest. Sassafras averaged 1776 seedlings/acre in Allen and Bowersox's study, and 1138/acre in the **D** stands and 4567 seedlings/acre in **DT** stands. Some differences among the studies may be attribuable to sampling time, because we sampled immediately after defoliation, while the other research was no fewer than five years following defoliation.

The abundance of yellow-poplar seedlings likely reflects high site productivity (Ostaff and others 1982), and yellow-poplar regeneration may aggravate problems of oak regeneration (O'Hara 1986). This species is likely to dominate certain areas if disturbance is severe (Beck and Hooper 1986). Loftis (1983) found that any canopy opening is likely to promote yellow-poplar and lead to its dominance on good sites in the southern Appalachians. In the current study, the most abundant 1-5 feet regeneration of yellow-poplar occurs on thinned stands and thinned/defoliated stands. However, our data suggest that recruitment into the larger size classes for this species (Table 5) has been minimal. This species has increased relative to total basal area, in the overstory on two of the three **DT** stands, but increased only slightly elsewhere (Table 1) during the four year period. The increase in overstory corresponds to oak mortality in the highly disturbed stands.

In this study, black cherry seem to be assuming a role analogous to yellow-poplar in the southern Appalachians. Although total numbers of black cherry seedlings decreased over the four years of the study, the decreases were apparent in the smallest size classes. The seedlings in size class 3 increased significantly in the three disturbed treatments (Table 5). Black cherry is relatively intolerant of shade and will respond favorably when the canopy has been opened (Marquis 1990). A substantial cohort of black cherry was established pre-defoliation and pre-thinning

CONCLUSIONS

Black cherry is likely to dominate the next generation of overstory trees in the stands in this study and in comparable areas in the Allegheny Plateau. Disturbance accelerates this transition, but the response of black cherry to defoliation and defoliation plus thinning was similar. Recruitment of black cherry into the taller size classes stands that were thinned only was slightly less than stands that were thinned and defoliated and defoliated only, underscoring the importance of disturbance for black cherry success.

Despite an abundance of shade intolerant species in the understory of these stands and an increase in the number of seedlings and saplings less than a foot tall, few of these will become canopy dominants. Recruitment into the larger size classes of these species has been minimal.

Defoliation reduced the growth and recruitment of oak, but thinning moderated the defoliation effect. Thinning, without defoliation, enhanced growth of oak seedlings. Even in undisturbed stands, however, oak regeneration over 5 feet tall was negligible after four years.

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TWO-YEAR RESULTS OF HERBICIDE RELEASED, NATURALLY-REGENERATED BOTTOMLAND CHERRYBARK AND SHUMARD OAK SEEDLINGS

John F. Thompson Jr. and Larry E. Nix[1]

Abstract: After clearcuting in bottomlands, oak seedlings that naturally regenerate are often overtopped by woody pioneer species, sprouts and herbaceous material. To improve the competitive status of three- to four-year-old oak seedlings in two bottomland stands in South Carolina, several herbicides and methods of application were used to kill and/or stunt the overtopping competition. Oak seedling diameter growth two years after treatment was nearly doubled by four of the late summer herbicide oversprays and by two of the directed applications. Height growth two years after treatment was increased by 1.9 to 2.7 feet by two of the oversprays and by one of the directed soil applications. Timing the oversprays so that competing vegetation shielded the oak seedlings from herbicide damage appeared to aid in improving the oak seedling's competitive position in the rapidly developing dominant canopy.

INTRODUCTION

In the past thirty years oak (*Quercus* sp.) has been decreasing in the bottomland hardwood stands of the Southern United States (Johnson 1984). Cherrybark oak (*Quercus pagoda* Raf.) and Shumard oak (*Quercus shumardii* Buckl.) are two high quality bottomland oak species (Miller and Lamb 1985) that are not being replaced in the bottomland hardwood forest. The ecology and biology of bottomland oaks have been investigated to determine why the number of oaks are decreasing in new stands of the bottomland forests (Johnson 1979, Guldin and Parks 1989, Clatterbuck and Hodges 1988, Hodges and Janzen 1987). Because of their slow early growth, newly established oak seedlings cannot compete successfully with sprouts and fast-growing pioneer species. Oak seedlings often grow and die back for 4 to 6 years after germination before they reach a stage of rapid height growth. The slow growth of oak seedlings after germination is compounded by animal predation and overtopping by briars, sprouts, and early successional trees and brush (Gingrich 1979, Watt 1979, Hannah 1987, Nix 1989). However, if released oak seedlings can respond and achieve a dominant position in the developing canopy (Nix 1989).

Some type of release of oak seedlings after clearcutting is usually needed to have oaks in the dominant canopy in a reasonable period with quality, size, and grade (Beck 1970, Hannah 1987). Release should be accomplished 3 to 5 years after clearcutting to allow the seedling oaks to quickly catch up with the other woody species on the site (Beck 1970). Early release should allow the oaks to be a dominant component of the canopy by the time the stand is 25 years old. Early release may also shorten the normal oak rotation by 10 to 15 years for quality oak products (Clatterbuck et al. 1985, Clatterbuck and Hodges 1988). Release of crop trees with herbicides has been accomplished successfully for many years in the management of pine stands (Clason 1978, Nelson et al. 1985, Bacon and Zedaker 1987, Nelson and Cantrell 1990). Therefore, it should be possible to release oak seedlings with careful application of the same herbicide.

During the winter of 1987 and 1988, two bottomland hardwood stands with a 40-percent oak component (basal area basis) were clearcut along the Congaree River in South Carolina. These stands apparently had a good seed crop prior to harvest, as from 3- to 5-thousand oak seedlings per acre were established (Nix and Lafaye 1993). When first examined, in the winter of 1989, these oak seedlings were overtopped by a dense canopy of blackberry, herbaceous composites, and woody seedlings and sprouts. This study was implemented to evaluate several herbicides and application methods for releasing overtopped oak seedlings developing in dense young clearcuts.

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PROCEDURE

Forty-two plots approximately 18- to 22-feet wide and 25- to 130-feet long were located along two-foot wide transects cut through the vegetation of a three- and a four-year-old clearcut, approximately one-half mile apart in the first bottom of the Congaree River near Columbia, South Carolina. The transects were placed where two or three cherrybark or Shumard oak seedlings in each of three height classes were found in an overtopped condition. The plots were placed at least 15 feet apart to reduce the chance of one herbicide treatment influencing any adjoining treatment. Each plot contained 6 to 9 seedlings located along either side of the transect. Seedlings were chosen within approximately 7 to 9 feet of the transect, but at least 2 feet away such that the cut transect did not affect the seedlings' competitive status. The seedlings were selected to be approximately 6+ feet apart to accommodate the directed herbicide treatments. The length of the plot was determined by the distribution of the seedlings and the width of the plot was determined by the overspray width and the spray apparatus boom height. The beginning and end of each plot center line was marked by a white, 4-foot, plastic pipe driven into the ground.

The treatment plots were blocked for replication according to preliminary estimates of total competition (based on a height/distance index) (Daniels 1976) on the plots (high, medium or low). Three replications of the treatments were arranged with each treatment plot was randomly placed in each of the three blocks. The oak seedlings chosen for measurement were statistically similar in height on all plots. The preferred condition of the seedlings for release was overtopped, but at least 12 inches in height. Each plot contained at least two seedlings and, if possible, three seedlings in each of the three following height classes: 1-Foot Class) 1 to 1.9 feet, 2-Foot Class) 2 to 2.9 feet, 3-Foot Class) 3 feet and taller. Each seedling chosen was marked by a wire flag and metal tag bearing a coded number.

Preliminary treatments with a quick-browning herbicide in 20% increments of the recommended release rates for pines were applied after full foliage development (mid summer) to refine the rates that were used in the treatments. The methods of treatment, herbicides, and rates which were applied in late July/early August were as follows:

Control - no treatment.

Directed (Streamline) - Application of 20% Garlon 4 (a triclopyr herbicide), 10% Cide-Kick II surfactant (JLB 1984) and 70% diesel fuel applied to the lower portion of all competing stems in a 3+ foot radius around the oak seedlings (Dow 1988, McLemore and Cain 1988, Yeiser et al. 1989). This application was accomplished with a Solo piston backpack sprayer equipped with a D2 orifice disc tip for stream application.

Directed (Spot gun) - Application of Velpar L (a hexazinone herbicide) or Escort (a metsulfuron benzoate herbicide) applied in a grid pattern of 6 - 1 milliliter spots placed approximately 3.5 feet from the oak seedlings to be released. The spots of Velpar L consisted of a mixture of Velpar L and water that was 50% of the manufacturer's product strength. The application mixture of Escort consisted of 1 oz. of Escort mixed in 2 gallons of water. Due to the fine texture of the soils on the study site, the manufacturer's rate of application for use on this texture of soil indicates that there will be a 1.5- to 2-foot non-toxic zone around the treated oak seedlings (Du Pont 1987, Rachal et al. 1988, Du Pont 1988). These applications were accomplished with a standard spot gun applicator calibrated at 1 milliliter per spot application.

Broadcast (Overspray) - Simulated aerial broadcast, an overspray applied with a boom apparatus, applied at one half and full label-recommended application rate of commercial herbicides for releasing pines with 3.2 oz. per acre of TimberSurf 90 surfactant (0.25% v/v -- commonly recommended rate in release of pines) (Timberland ca.1989) at 10 gallons total mix per acre (Dow 1988) for each of the herbicides in Table 1. The simulated aerial broadcast spray was accomplished with a CO^2-pressurized backpack apparatus with a boom extended well above the vegetation (16 feet above ground) and equipped with a single horizontally aligned flood jet nozzle. The actual area treated was calculated by using the length of the plot, the boom height, and the nominal spray width within which competing vegetation would be uniformly treated (18 to 22 feet). The spray time, spray pressure, boom height, and amount of herbicide to be used were predetermined. Measurements of the spray time and pressure were recorded for each plot so the actual rate of application could be calculated. Spray width ranged from 18 to 22 feet depending on height of competing vegetation and number of boom sections installed, but within which competition was uniformly treated.

Table 1. Simulated aerial broadcast applications (oversprays) that were used at 100% and 50% of standard pine release rates for oak release in 3- and 4-year-old clearcut bottomland hardwood stands in South Carolina.

Herbicide	Standard Pine Release Rate
Garlon 4	1.5 qt/ac
Escort	1 oz/ac
Accord	1.5 qt/ac
Velpar L	3 qt/ac
Arsenal AC/Escort	8 oz - 0.25 oz/ac[1]

[1]The rate of 0.25 oz/ac of Escort remains the same for both the 100% and the 50% rate plots.

To determine effectiveness of the release treatments, herbaceous competition, woody competition, total competition, seedling height, and GLD (ground line diameter), were measured before and after treatment. The results of the initial reduction of competition in this study were reported in an earlier paper (Thompson and Nix 1993). Seedling height (± 0.1 foot) and GLD (± 0.1 inch) were measured after two years of growth. Data were analyzed using a complete random block design and PC-SAS (1992), Anova procedure. Means were tested at the 0.01 level of probability.

RESULTS AND CONCLUSIONS

The effectiveness of any crop tree release treatment can be judged early by the subsequent tree height and diameter growth. In this study, oak seedling height and diameter growth two years after treatment are the major criteria for evaluating the effectiveness of the herbicide release treatments. Two treatments resulted in a significant increase in height growth of released oak seedlings after two full growing seasons (Table 2). Seedlings released by the low rate, broadcast application of Escort and the high rate, broadcast application of Arsenal/Escort grew 1.5 and 0.9 feet, respectively, more than the untreated seedlings (all height classes combined). Velpar L, soil-applied by spot gun, apparently increased seedling height growth (1.2 feet more then the control); however, no difference could be statistically detected because of high variance. Nine of the thirteen treatments significantly increased oak seedling ground line diameter (GLD) as compared to the untreated seedlings (Table 2).

Table 2. Two year height and diameter growth (all seedling height classes combined) of cherrybark and Shumard oak seedlings after herbicide release in three and four year-old clearcut bottomland hardwood stands on the Congaree River in South Carolina.[1]

Herbicide Treatment	Height Growth	Diameter Growth	Damaged[3]
	-- ft --	-- inches --	-- % --
BROADCAST[2]			
ACCORD HIGH	5.6	0.68**	9
ACCORD LOW	5.9	0.68**	4
ESCORT HIGH	5.5	0.78***	9
ESCORT LOW	7.0**	0.70***	0
VELPAR L HIGH	6.1	0.72***	4
VELPAR L LOW	5.9	0.51	0
GARLON 4 HIGH	4.8	0.84***	17
GARLON 4 LOW	5.4	0.73**	14
ARSENAL/ESCORT HIGH	6.4*	0.67	0
ARSENAL/ESCORT LOW	4.0	0.39	14
SPOT GUN			
ESCORT	6.2	0.56	0
VELPAR L	6.7	0.85***	8
STREAMLINE			
GARLON 4	4.8	0.99***	29
CONTROL	5.5	0.48	0

[1]Numbers with *, **, and *** adjacent, differ only from the control at the 0.10, 0.05, and 0.01 level of probability, respectively.
[2]High indicates 100% pine release rates. Low indicates 50% pine release rates.
[3]Damaged indicates the percent of the seedlings that were either killed down to the rootstock and are resprouting or have died.

The lack of significant increase in height or GLD in the 1-foot height class, except in the most drastic treatment (Tables 3 and 4), indicates that seedlings less than two feet in height at this age would not respond to the release treatments. The 2- and 3-foot height class oak seedlings, however, would respond as indicated by the number of treatments that significantly increased seedling GLD (Table 3). Nine treatments and seven treatments of the 2- and 3-foot height class seedlings, respectively, significantly increased the GLD as compared to the untreated seedlings. However, in only four treatments in the 2- and 3-foot height class were seedlings significantly taller than the untreated seedlings.

One possible reason for the lack of significant height growth response is that the released oak seedlings appear, by casual observation, to have larger and fuller crowns than the control seedlings or oak seedlings that had less reduction in competition (Thompson and Nix 1993). Another reason for less height growth by released seedlings may be the lack of close trainer seedlings/trees. Again, from casual observation the oak seedlings that were released enough to obtain some direct sunlight, but that have close (within 3 feet), taller seedlings/trees seemed to achieve more height growth than other oak seedlings.

Table 3. Two year diameter growth (according to initial height class) of cherrybark and Shumard oak seedlings after herbicide release in three and four year old clearcut bottomland hardwood stands on the Congaree River in South Carolina.[1]

Herbicide Treatment	Diameter Growth/Height Class		
	1-Foot	2-Foot	3-Foot
		--inches--	
BROADCAST[2]			
ACCORD HIGH	0.29	0.69	0.95**
ACCORD LOW	0.39	0.90**	0.78
ESCORT HIGH	0.45	0.81**	1.12**
ESCORT LOW	0.47	0.71*	0.89**
VELPAR L HIGH	0.45	0.80**	0.87*
VELPAR L LOW	0.40	0.41	0.74
GARLON 4 HIGH	0.47	0.82**	1.08**
GARLON 4 LOW	0.40	0.90***	0.80
ARSENAL/ESCORT HIGH	0.49	0.76*	0.83
ARSENAL/ESCORT LOW	0.22	0.28	0.70
SPOT GUN			
ESCORT	0.47	0.51	0.72
VELPAR L	0.38	0.92**	1.15*
STREAMLINE			
GARLON 4	0.88**	1.10***	0.97**
CONTROL	0.42	0.47	0.58

[1]Numbers with *, **, and *** adjacent, differ only from the control at the 0.10, 0.05, and 0.01 level of probability, respectively.
[2]High indicates 100% pine release rates. Low indicates 50% pine release rates.

CONCLUSIONS

It is possible to release oak seedlings in young (3 to 4 year old) clearcuts without serious losses with careful application of selected herbicides, especially if the oak seedlings are in an overtopped condition. This overtopping, which is very common in such clearcuts, seems to protect (shield) the seedlings from lethal amounts of the herbicides. Although only two treatments induced a significant increase in seedling height growth at present (2 years after treatment), nine of the thirteen treatments caused a significant increase in diameter growth; one, the streamline application caused more than double the diameter growth of the control. It may be too early to ascertain the full effect of this release on height growth as the oak seedlings appear at present to be gaining biomass from the increased sunlight, as indicated by the increased GLD. Some of these treatments appear to have potential for establishing more oaks in the main canopy at an earlier age, thereby increasing the oak component and basal area of the young stand.

These are two-year results; and because of the oak developmental pattern, the seedlings need several more growing seasons before the full treatment effects can be determined. Evaluation of the treatments in the future and an economic analysis will better assess the full practicality of such herbicide release of young overtopped oaks in recently clearcut bottomland hardwood stands.

Table 4. Two year height growth (according to height class) of cherrybark and Shumard oak after herbicide release in three and four-year old clearcut bottomland hardwood stands on the Congaree River in South Carolina.[1]

Herbicide Treatment	Height Growth/Height Class		
	1-Foot	2-Foot	3-Foot
		--feet--	
BROADCAST[2]			
ACCORD HIGH	3.6	5.5	7.1
ACCORD LOW	4.0	7.6*	6.5
ESCORT HIGH	5.4	5.9	5.3
ESCORT LOW	6.0	6.9	7.8**
VELPAR L HIGH	5.5	6.4	6.4
VELPAR L LOW	5.3	5.6	7.0
GARLON 4 HIGH	2.9	5.2	5.7
GARLON 4 LOW	3.4	6.8	5.1
ARSENAL/ESCORT HIGH	6.1	6.7	6.5
ARSENAL/ESCORT LOW	2.3	3.4	6.5
SPOT GUN			
ESCORT	5.9	6.4	6.4
VELPAR L	3.4	7.8**	8.2**
STREAMLINE			
GARLON 4	4.8	5.8	3.7
CONTROL	5.2	5.7	5.5

[1]Numbers with * and ** adjacent, differ only from the control at the 0.10 and 0.05 level of probability, respectively.
[2]High indicates 100% pine release rates. Low indicates 50% pine release rates.

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SITE PREPARATION FOR RED OAK PLANTATION ESTABLISHMENT ON

OLD FIELD SITES IN SOUTHERN INDIANA

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Abstract: Little research has been conducted on the use of mechanical site preparation or fertilization in the Central Hardwood Region. Many hardwood plantings, particularly oak plantings, on old field sites in the region have resulted in high rates of mortality, stem die-back, and slow early-growth rates. The purpose of this study was to investigate the effect of mechanical site preparation techniques and fertilization on the early survival and growth of northern red oak (*Quercus rubra* L.) seedlings planted on an old field site in southern Indiana. The study was initiated in the Spring of 1993 on a severely eroded old field site, which had a history of successive plantation failures. The treatments included all possible combinations of subsoiling, tillage, and fertilization. Each treatment combination was replicated four times. Subsoiling was accomplished to a 45 - 50 cm depth. Conventional tillage consisted of a three bottom moldboard plow followed by disking to a tillage depth of approximately 25 cm. Fertilization consisted of 336 kg nitrogen/ha, 98 kg phosphorus/ha, 93 kg potassium/ha, 224 kg calcium/ha, 56 kg magnesium/ha, 112 kg sulfur/ha, and 560 kg lime/ha. Seedling survival, diameter and height growth, root growth parameters, and foliage nutrient concentrations were measured. Deer browsing was also monitored. After one growing season, survival exceeded 99% over all treatments. Fertilization produced a 47% and 60% increase in height and diameter growth, respectively, over the unfertilized treatments. Subsoiling and tillage did not appear to significantly increase tree stem growth. Fertilized seedlings had higher foliar N concentrations, dark green foliage and 2.1 growth flushes during the first growing season compared to the yellow-green foliage and the 1.2 growth flushes produced by unfertilized seedlings. Fertilized trees were favored by the deer for browse, but resprouted vigorously following browsing. Nitrogen was the main factor limiting tree growth. Fertilization enhanced height growth by inducing multiple growth flushes throughout the growing season. Because the results of this study are preliminary, treatment effects will be monitored through the establishment phase of the plantation.

INTRODUCTION

The land-use history of southern Indiana is typical of the Midwest. From the early 19th century to the present, there has been a repeated cycle of land clearing, agronomic crop production and livestock grazing, soil erosion, declines in soil fertility, abandonment, natural succession, and once again, clearing (Callahan 1973). Within the past 30 years, economics and government farm policies have generated land clearing/reforestation cycles.

In the past, reforestation of old fields occurred through natural succession, resulting in dense stands of sassafras and other low-value species. High-value timber species such as the oaks were established only after long periods of time. Government cost-share programs such as Conservation Reserve Program (CRP) and Stewardship Incentive Program (SIP) along with upward price trends in hardwood timber markets have encouraged more landowners to realize the potential value of high quality hardwood forests. More and more landowners desire to establish hardwood plantations of known stocking. There has been mixed success with hardwood plantings on old field sites in southern Indiana. Repeated stem dieback or extremely slow initial growth often results in high mortality and subsequent low stocking (McGee and Loftis 1986, Pope 1993, Russell 1971).

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Much of the research on artificial regeneration of oaks in the *Central Hardwood Region* has concentrated on tree improvement, planting stock improvement, mycorrhizal inoculation, weed control, vertebrate pest control, and the use of tree shelters (Pope, 1993). Intensive plantation establishment measures, such as mechanical site preparation and fertilization, have not been as extensively investigated in the region. Mechanical site preparation has been studied quite extensively and is widely accepted in the south particularly with the regeneration of southern pine (Berry 1979, Burger and Pritchett 1988, Lantagne and Burger 1983, Miller and Edwards 1985, Morris and Lowery 1988). Malac and Heeren (1979) discuss the use of disking and subsoiling for improving soil conditions and reducing perennial herbaceous weed competition when establishing oaks in old fields. Seifert and others (1985) studied the effects of bedding and disking on the establishment of swamp chestnut oak (*Quercus michauxii* Nutt.) on a poorly drained site in southeastern Indiana. After five growing seasons, 52% of the seedlings in the disked treatment and 45% in the disked and bedded treatments were taller than the overall mean seedling height (152 cm) compared to 16% for the control seedlings. Subsoiling fractures restrictive layers thus allowing deeper root penetration early in the tree establishment phase and providing a greater volume of soil for root exploitation (Berry 1979, Lantagne and Burger 1983). Miller (1993) outlines a "general plantation establishment prescription" for oaks including the use of mechanical site preparation.

Fertilization has been extensively researched and widely practiced in coniferous forests of the South and the Pacific Northwest (Allen 1987), but relatively few studies have examined hardwood species response to fertilization. Foster and Farmer (1970) reported significant growth responses following nitrogen fertilization of planted northern red oak in Tennessee. Auchmoody and Smith (1977) reported on the response of natural yellow-poplar and red oak stands to fertilization in West Virginia. Johnson (1980) studied the effects of fertilization with 112 kg N/ha and 244 kg P/ha on five different species of oak seedlings planted in the Missouri Ozarks. Following eight growing seasons, fertilization significantly improved scarlet oak (*Quercus coccinea* Muenchh.) survival and significantly increased the number of black oaks (*Quercus velutina* Lam.) and scarlet oaks attaining a 6, 8, and 10 feet minimum height. Northern red, white (*Quercus alba* L.) and post (*Quercus stellata* Wangenh.) oaks did not respond significantly to fertilization.

The purpose of this study was to investigate the effect of the following three intensive site preparation methods and their combinations on first growing season survival and growth of northern red oak (*Quercus rubra* L.) seedlings planted on an old field site in southern Indiana:

1. subsoiling
2. tilling (plowing & disking)
3. fertilization.

METHODS

Site Description

The study was initiated in the Spring of 1993 on a one ha old field site located in the unglaciated sandstone-shale uplands of southern Indiana, in the Crawford Upland Section of the Shawnee Hills Natural Region (Homoya and others, 1985). The site was abandoned from agricultural use approximately 40 years ago. The soils are characterized by moderately thick loess deposits over paleosols on residuum formed from acid siltstone and sandstone. Because of past management history, most of the loess cap has been eroded away. The soils are fine-silty, mixed, mesic Typic Fragiudalfs of the Zanesville series, with a fragipan at a 60 cm depth. Because of the fragipan, the site has a perched water table during the winter and spring. The site is a south facing aspect with a 6% slope. It is severely eroded, presently dominated by broomsedge, and has a history of plantation failures. The average growing season temperature is 26°C, and average annual precipitation is 92.7 cm.

Study Design and Installation

The experimental design was a completely randomized 2x2x2 factorial with a split plot (nested design), with 4 replications and a total of 32 whole plot treatment units. The area of each whole plot treatment unit was 95 m^2. The whole plot treatments consisted of factorial combinations of subsoiling, tilling, and fertilization. The following are the eight treatment combinations:

1. control
2. fertilize
3. subsoil
4. subsoil + fertilize
5. till
6. till + fertilize
7. subsoil + till
8. subsoil + till + fertilize.

Subsoiling was accomplished in late April 1993 using a single-tine subsoiler drawn by a 80-horse-power farm tractor; equipment readily available to most landowners within the region. This produced a 45-50 cm deep slit. This was not sufficient to fracture the fragipan, but did produce a zone of fracture in the dense, clayey B_t soil horizon. In mid-May, tilling was accomplished by plowing with a 3-bottom moldboard plow followed by disking to a 20-25 cm depth.

Fertilizer was applied in late April 1993, prior to plowing and disking. Fertilization consisted of a broadcast application of urea, monoammonium phosphate, potassium-magnesium sulfate, and a fast-reacting pelletized calcitic lime, resulting in the application of 336 kg N/ha, 98 kg P/ha, 93 kg K/ha, 224 kg Ca/ha, 56 kg Mg/ha, and 112 kg S/ha. These fertilizers were chosen to provide an ample supply of all plant macronutrients and to ensure that none of these elements would become limiting (Blinn and Buckner 1989).

Within each of the 32 whole plot treatment units, three different types of 1-0 northern red oak seedlings were planted. Seedling type or planting stock was the split or nested plot treatment. The following describe the three seedling types and the number planted in each split plot treatment (Table 1):

1) 15 standard state nursery seedlings; average caliper 5.7 mm; average height 44.5 cm.

2) 4 bareroot seedlings grown under enhanced nutrient and moisture regime; average caliper 6.3 mm; average height 50.1 cm.

3) 5 containerized seedlings grown under enhanced nutrient and moisture regime; average caliper 5.8 mm; average height 49.1 cm.

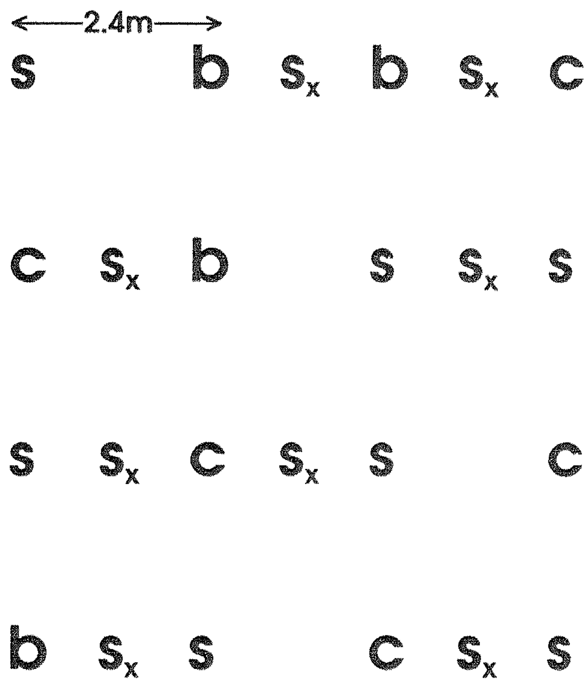
A total of 24 seedlings were planted in random fashion in each whole plot treatment unit in mid-May. All but eight of the standard state nursery seedlings were hand planted using a post hole digger on a 2.4 m x 2.4 m spacing. Trees were planted directly into subsoiled slits where that treatment occurred. All planting rows were carefully surveyed prior to treatment installation so that subsoiled slits could be readily relocated where subsoiling was followed by disking. The remaining eight standard state nursery seedlings were planted with a post hole digger on a 1.2 m x 2.4 m spacing for later excavation and root growth analyses (Figure 1).

Chemical weed control was applied uniformly over all treatments and consisted of the application of a tank mixture of simazine and atrazine, each at a rate of 2.24 kg a.i./ha at the time of planting, and glyphosate at a rate of 2.66 kg a.i./ha in July. Herbicide was applied with a backpack sprayer in 110 cm bands in the planting row. Care was taken to prevent drift onto the seedlings during the glyphosate application.

Table 1. Mean diameter growth and height growth for three different northern red oak planting stock.

Planting Stock	n	Diameter Pre-plant	Diameter Year 1	Diameter Growth	Height Pre-plant	Height Year 1	Height Growth
		(mm)			(cm)		
Std. Nurs.	480	5.71 a[1]	7.69 a	1.86 a	44.5 a	57.6 a	12.2 a
Spec. Bare.	128	6.30 b	9.20 b	2.90 b	50.1 b	71.3 b	21.2 b
Spec. Cont.	160	5.76 a	10.05 c	4.22 c	49.1 b	71.5 b	21.9 b

[1]Different letters indicate statistically significant differences at α=0.01 level of significance.



s = standard nursery stock
s_x = standard nursery stock - excavate
b = enhanced bareroot stock
c = enhanced containerized stock

Figure 1. Example of the layout of a single whole plot treatment unit.

Measurements

Caliper and height were measured on all seedlings prior to planting. The trees were measured for total height and groundline diameter following the first growing season (1993). The number of growth flushes for each seedling were recorded as well as evidence of deer browse. On November 1, 1993, observations on tree dormancy were made. The number of trees that were not yet completely hardened off were recorded.

Following the first growing season, four of the eight standard state nursery seedlings planted for later excavation were randomly selected from each whole plot treatment unit and carefully excavated to obtain the entire root system. Lateral root development, in both a north-south and an east-west direction, and total root depth were measured in the field at the time of seedling excavation. A root volume index (RVI) was calculated by using the average between north-south and east-west lateral root extent measurements and the total root depth in the formula for the volume of a cylinder. This provided an index of the soil volume exploited by the roots.

First order laterals greater than 1 mm in caliper were counted on each of the excavated seedlings. Total length of first and second order laterals greater than 1 mm in caliper were also measured. Excavated seedlings were then clipped to sever roots from stem, oven dried at 65°C to a constant weight, and weighed to obtain stem biomass, root biomass, and total biomass. Root:shoot ratios were also calculated.

Foliar Analysis

In late July 1993, one fully expanded leaf from the top one-third of the crown was sampled from each tree in each whole plot treatment unit. All leaves sampled from a single whole plot unit were composited. Leaf samples were oven dried at 65°C and ground to pass a 1 mm sieve. Total nitrogen was determined using the micro-Kjeldahl method described by Nelson and Sommers (1973). Total P, K, Ca, and Mg were determined using wet digestion in nitric acid and hydrogen peroxide followed by analysis by inductively-coupled plasma emission spectrometry (ICP).

Data Analysis

Availability of the different seedling types used in this study precluded planting equal numbers of each type within each whole plot unit. Because of the resulting unbalanced designed, a general linear model analysis of variance (GLM-ANOVA) was used to test for overall treatment differences. In analyzing the site preparation treatment effects, the means of all three seedling types were pooled. To provide for temporal consistency in the study, the trees that were excavated in 1993/94 were excluded from the analysis of stem parameters. Root parameter data was of course only collected on the excavated trees. Fisher's least-significant difference (LSD) mean separation procedure was used to find individual treatment differences following the GLM-ANOVA. Correlations between foliage nutrient concentrations and tree growth parameters were made using simple linear regression.

RESULTS AND DISCUSSION

With the exception of mole damage to three seedlings in one of the control plots, herbicide damage to one seedling in one of the disked and fertilized plots, and damage caused by unknown agents to two other seedlings, each in separate plots, survival was over 99% across all treatments following one growing season. This may be in part attributable to the above normal rainfall that occurred throughout parts of the growing season; e.g., growing season precipitation averaged 2.4 cm/month above normal.

Planting Stock

Both the bareroot and containerized stock grown under enhanced moisture and nutrient conditions were significantly taller at the time of planting than the standard nursery stock (Table 1). After one growing season both the bareroot and containerized special planting stock were about 71 cm in height compared to 58 cm for the standard stock and they had over 75% greater height growth than the standard stock. Although the special containerized stock did not have significantly greater diameter than the standard stock at the time of planting, following one growing season it did have 46% and 127% greater diameter growth than the special bareroot stock and the standard nursery stock, respectively. No significant interactions were detected between planting stock and site preparation treatments, therefore different seedling types did not respond in a different manner to the various treatments (Figure 2).

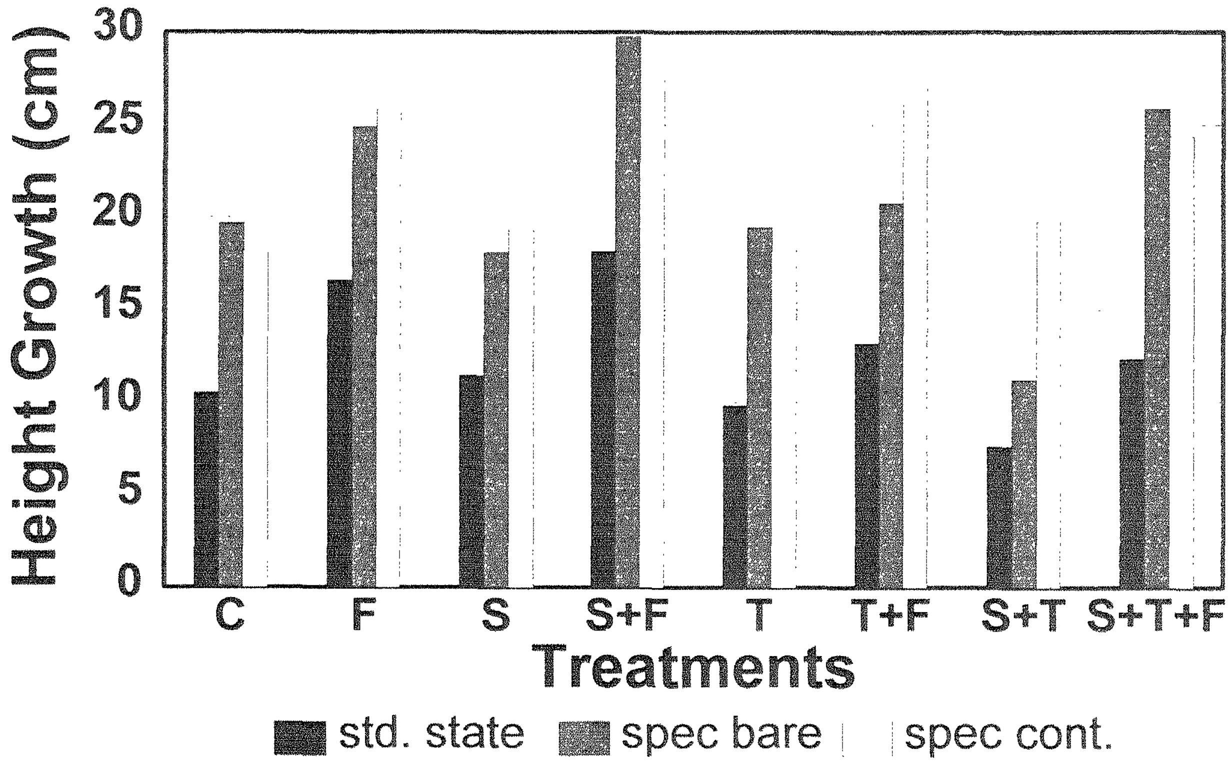


Figure 2. Year 1 height growth of northern red oak by site preparation treatment combination and seedling type.

It is generally believed that larger hardwood planting stock performs better upon outplanting than smaller planting stock (Gordon 1988, Stroempl 1985, Zaczek and others 1991). The results of this study concur with the conclusions of previous research.

Site Preparation Treatments

Root morphological characteristics. With the exception of root depth, subsoiling had little effect on root characteristics following one growing season. The roots of excavated red oak trees growing in subsoiled treatments penetrated to an average depth of 54.2 cm in the first growing season, compared to 48.3 cm for the non-subsoiled treatments (Table 2). In a year of normal or below-normal precipitation, root depth penetration during the first growing season following planting may be more critical to tree survival and growth. However, unless there is a hardpan within 45-50 cm of the soil surface, subsoiling may not produce enough additional tree growth to justify costs. On the other hand, many tree planting machines are equipped with a deep set shoe that produces a similar effect to subsoiling. Rooting depth may prove to be an important factor in subsequent years of the tree establishment phase.

Table 2. Root morphological parameters for excavated standard state nursery seedlings growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	Depth[1]	Root[2] Volume Index	1st & 2nd[3] Order Lateral Length	No.[3] 1st Order Laterals	Fibrous	Biomass[4]	Root: Shoot
		(cm)	(cm^3)	(cm)		(%)	(g)	
Subsoil								
No	64	48.3 a[5]	183097	554	17.7	39	45.0	1.37
Yes	64	54.2 b	229473	582	18.7	23	46.5	1.37
Till								
No	64	49.9	162296	507	17.4	20 a	43.4	1.36
Yes	64	52.6	250273	629	19.0	42 b	48.1	1.38
Fertilize								
No	64	48.8	170525	523	17.8	47 a	42.6 a	1.38
Yes	64	53.7	242045	614	18.5	16 b	49.0 b	1.36

[1]Total depth of root penetration into the soil.
[2]Calculated from the mean of the north-south and east-west measured lateral root extent and root depth used in the formula for a cylinder. Meant to approximate the total volume of soil being exploited by the root system.
[3]Caliper greater then 1 mm.
[4]Oven-dry weight of roots
[5]Different letters indicate statistically significant differences at α=0.05 level of significance.

Tilling, as well, appeared to have little effect on root characteristics (Table 2). Although the mean rooting volume index for the tilled treatment was substantially larger (54%) than that for the non-tilled treatment, the inherently high level of variation precluded any differences from being statistically significant.

Fertilization resulted in trees with greater total root biomass (49 g) than non-fertilized trees (42.6 g) (Table 2). Fertilization did not affect the root:shoot ratios of the trees. None of the treatments had a significant effect on the number of first-order lateral roots greater than 1 mm in diameter nor on the total length of first- and second-order lateral roots greater than 1 mm in diameter.

The importance of early root growth and development in northern red oak seedlings is reported in Grime and Jeffrey (1965). Crow (1988) underscores the importance of a "large, well-developed, well-established root system" as a "key factor related to rapid seedling growth." Repeated shoot dieback is reported to be an adaptive strategy of northern red oak in building up a sufficiently large root system and increasing the root:shoot ratio. Fertilization may aid in the early development of a larger root system without the loss of stem growth due to dieback.

Stem growth. Fertilization increased height growth by 47% and resulted in a mean tree height over 5 cm greater than that for non-fertilized trees after one growing season (Table 3). Fertilization also increased diameter growth by 60%. There were no significant interactions in height growth among site preparation treatment effects (Figure 2). Neither subsoiling nor tilling increased height or diameter growth after one growing season. In fact tilling appeared to have a marginally negative, though not statistically significant effect on height growth. Both tilling and fertilization produced greater stem biomass in the excavated trees, while fertilization alone produced greater total tree biomass than non-fertilized treatments (Table 3).

Table 3. Mean diameter and height growth for nonexcavated northern red oak averaged across all seedling types and stem biomass, and total tree biomass for excavated standard state nursery northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	Diameter Pre-plant	Diameter Yr. 1	Dia. Growth	Height Pre-plant	Height Yr. 1	Ht. Growth	Shoot[1] Biomass	Tot.[1] Biomass
		(mm)			(cm)			(g)	
Subsoil									
No	318	5.87[2]	8.76	2.80	47.6	66.5	18.3	32.5	77.5
Yes	318	5.98	9.21	3.19	48.2	67.1	18.5	34.0	80.5
Till									
No	318	6.00	8.81	2.79	47.8	68.1	20.1	31.8 a	75.2
Yes	318	5.85	9.15	3.19	48.0	65.5	16.8	34.7 b	82.8
Fertilize									
No	318	5.88	8.27 a	2.33 a	47.2	64.0 a	14.9 a	30.8 a	73.4 a
Yes	318	5.97	9.69 b	3.66 b	48.6	69.5 b	21.9 b	35.7 b	84.7 b

[1]Only includes excavated trees which were all standard nursery stock.
[2]Different letters indicate statistically significant differences at α=0.05 level of significance.

Fertilization increased the number of flushes during the growing season (Table 4). Non-fertilized trees averaged 1.2 flushes while fertilized trees averaged 2.1 flushes. Subsoiling did not influence numbers of flushes, but tilling negatively influenced the number of flushes. In fact there appeared to be an interaction between tilling and fertilization; tilling reduced the number of flushes occurring in fertilized treatments (Figure 3).

Tilling appeared to reduce the ability of fertilization to induce multiple growth flushes, in the first growing season. One explanation for this phenomenon might be the more open, harsh environment that tilling creates for the above-ground portion of the seedling. In non-tilled treatments, fertilization resulted in the growth of tall, luxuriant herbaceous vegetation between the planting rows. Excellent weed control within the planting row removed competition for moisture and nutrients but allowed between-row vegetation to moderate sunlight and wind exposure and thus moderate soil moisture and temperature and ambient air temperature immediately around the seedlings. Herbaceous growth between planting rows in the tilled treatments was low growing and relatively sparse. Crow (1988) cites a number of studies that indicate that northern red oak benefits from partial shade because of its moderating influence on temperature and evapotranspiration, while young, newly established seedlings may suffer from water stress under full sunlight. Thus, greater exposure that resulted from tilling may have reduced the trees' ability to produce multiple growth flushes, even under the favorable moisture conditions of the 1993 growing season and the abundant nutrient supplies of the fertilization treatment.

Tilling may have also resulted in increased N leaching losses. Unless surface soil compaction is a major concern, tilling may produce no early growth advantages where effective chemical weed control is used. Tilling also raises erosion and water quality concerns, particularly on the extremely erosive soils of the unglaciated region of southern Indiana. However, tilling may provide more long-term benefits that will be realized in future growing seasons.

There is a concern that excessive fertilization may delay winter dormancy in hardwoods and result in frost or winter damage. On November 1, 1993, 9% of the fertilized trees were not yet dormant, while only 1% of non-fertilized trees were not yet dormant (Table 4). This is not a perfect measure of the length of growing season created by the different

Table 4. Mean number of growth flushes, percent deer browse, and percent of trees hardened off as of Nov. 1, 1993 for nonexcavated northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	No. Flushes	Deer Browse	Percent of[1] Trees Not Hardened-off
			(%)	(%)
Subsoil				
No	318	1.56[2]	22	3
Yes	318	1.72	18	7
Till				
No	318	1.74 a	22	6
Yes	318	1.53 b	17	5
Fertilize				
No	318	1.20 a	13 a	1 a
Yes	318	2.08 b	27 b	9 b

[1]Trees with succulent growth and incompletely developed buds on the newest flush were considered not yet hardened off.
[2]Different letters indicate statistically significant differences at α=0.05 level of significance.

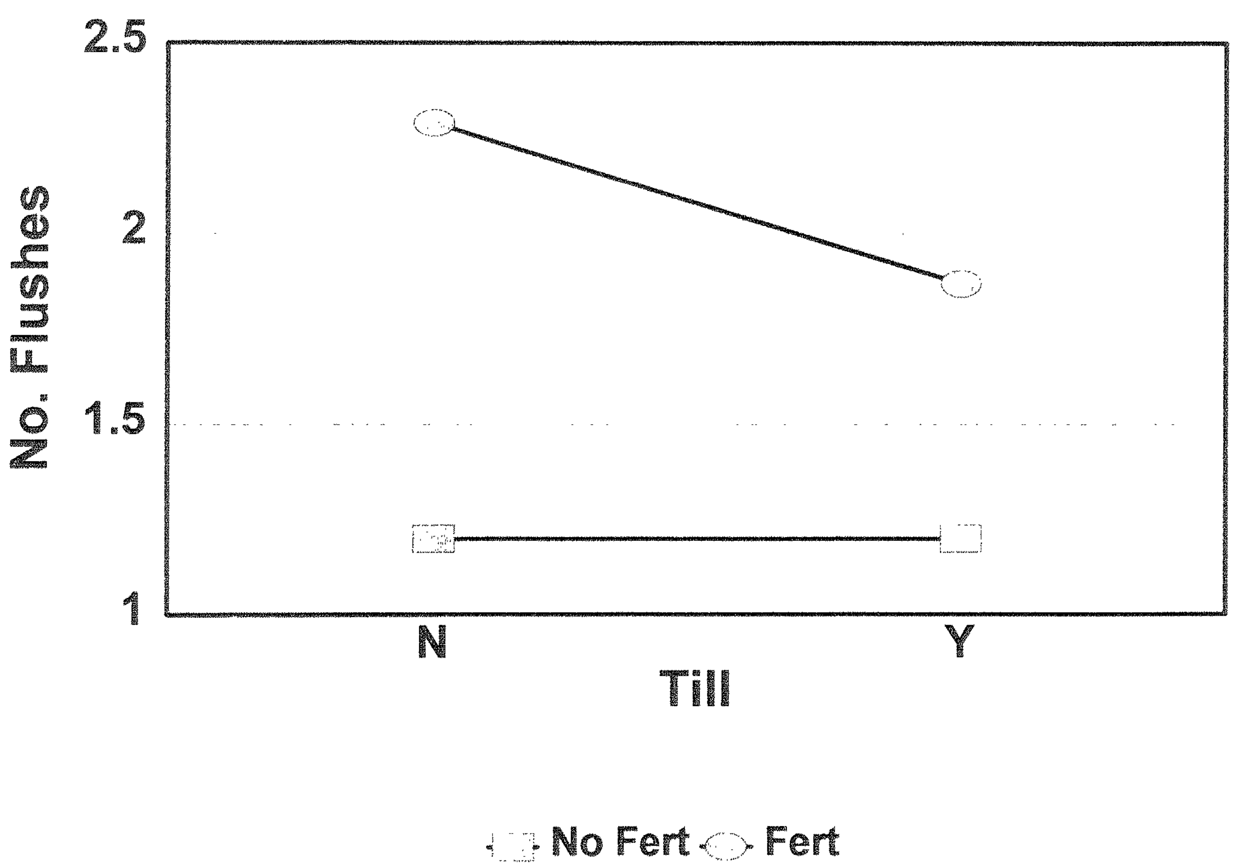


Figure 3. Interaction in the number of growth flushes between tilled treatments and fertilization treatments.

treatments, but it gives some indication of how fertilization may influence dormancy and stem hardening in anticipation of cold temperatures. The first frost at the study site occurred in mid-October while the first snow accumulation occurred in late October, 1993. Many of the fertilized trees still bore green leaves that did not show signs of impending senescence. The winter of 1993/94 was marked by below normal temperatures with periods of as long a one week where temperatures dropped to as low as -18° C. By April 1994, none of the seedlings in any of the treatments were damaged by the harsh winter conditions.

Many studies on hardwood regeneration in the *Central Hardwood Region* are incomplete without assessing the impacts of deer browsing. In fact, the deer seemed to prefer fertilized trees (Table 4). By the end of May of the first growing season, browsing had occurred on 27% of the fertilized trees while only 13% of the non-fertilized trees were browsed. In spite of the heavy browse, fertilized trees were able to respond to the browsing by reflushing and thus still outperformed the non-fertilized trees.

Nutrient relations. It appeared that in the first growing season, fertility was an overriding factor on this site. If any nutrients were possibly limiting tree growth, fertilization should not only produce an increase in growth rate but also increase concentrations of those nutrients in the foliage. Foliage nitrogen (N) concentrations (2.12 %) were significantly higher in fertilized trees than concentrations in non-fertilized trees (1.87 %) (Table 5). Phosphorus (P) and Calcium (Ca) concentrations were also significantly greater in the foliage of fertilized trees (0.11 % and 0.87 %, respectively) than non-fertilized trees (0.103 % and 0.78 %, respectively). Foliage potassium (K) and magnesium (Mg) concentrations did not respond to fertilization. Foliage color reflected these differences in nutrient concentrations. Most fertilized trees had dark green foliage while most non-fertilized trees had a greenish-yellow or even a very chlorotic appearance.

Table 5. Mean foliage nutrient concentrations for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	N	P	K	Ca	Mg
		(%)				
Subsoil						
No	16	1.97[1]	0.107	0.587	0.867	0.296
Yes	16	2.01	0.106	0.568	0.793	0.299
Till						
No	16	1.95 a	0.107	0.588	0.861	0.306
Yes	16	2.03 b	0.106	0.568	0.798	0.289
Fertilize						
No	16	1.86 a	0.103 a	0.588	0.782 a	0.293
Yes	16	2.12 b	0.110 b	0.568	0.878 b	0.301

[1]Different letters indicate statistically significant differences at α=0.05 level of significance.

Soil fertility appeared to be the main factor limiting tree growth. Therefore, height growth should be correlated with foliage N concentration. In fact, there was a significant relationship between height growth and foliage N concentration ($p < 0.0133$), following a simple linear regression, but the two variables were not strongly correlated (R^2 =0.16)(Figure 4). Neither P nor Ca concentrations were highly correlated with height growth and it is uncertain whether any other of the applied nutrients were necessary to produce this growth response. As increased N availability increases growth rates, demand for all other nutrients increases as well, therefore a balance of nutrients may produce a more long-term, sustained higher level of productivity.

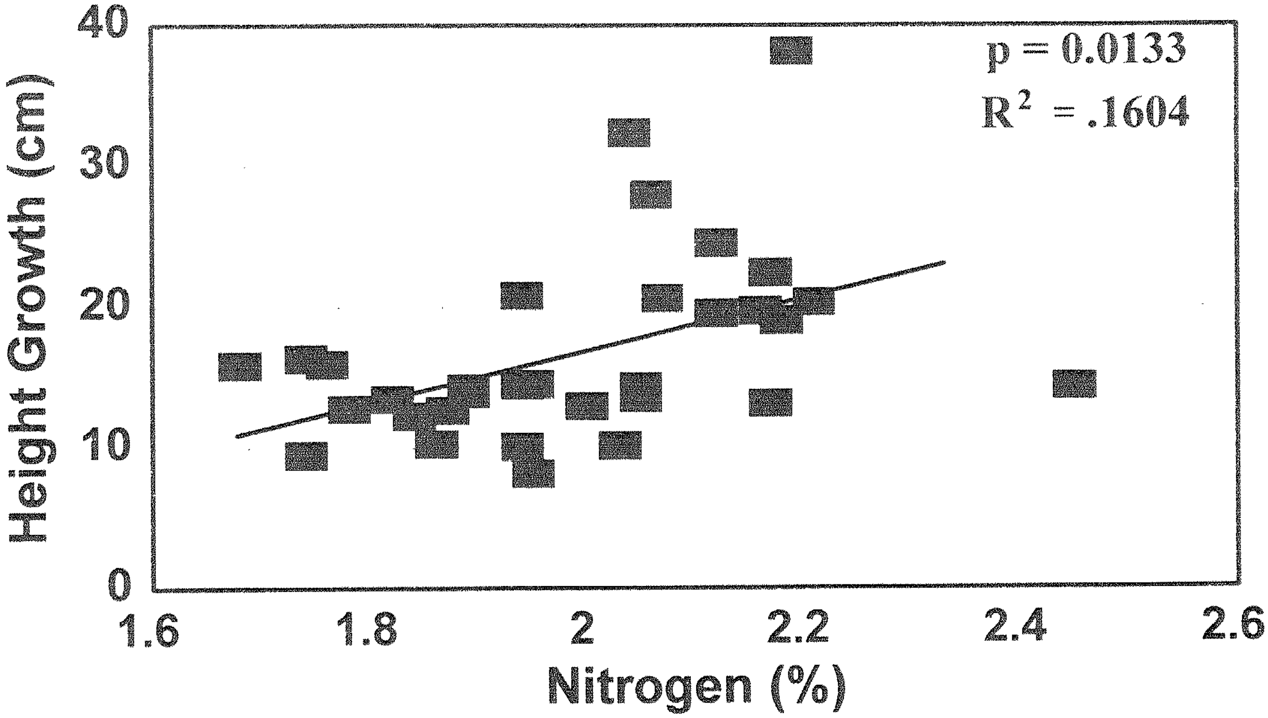


Figure 4. First-year height growth as a function of foliage N concentration for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Although there was not a strong correlation between height growth and foliar N concentration, the number of flushes as a function of foliage N concentration was highly significant (p>F=0.0001) and strongly correlated (R^2=0.45)(Figure 5). Height growth was also strongly correlated (R^2=0.56) with the number of growth flushes (Figure 6). Therefore, the increased availability of N appeared to increase height growth indirectly by increasing the number of flushes during the growing season. Longman and Coutts (1974), Borchert (1975), and Reich et al. (1980) all reported on the occurrence of episodic shoot growth of northern red oak or other oak species; episodic shoot growth defined as periods of shoot elongation interspersed by periods of rest within the same growing season. Crow (1988) reported that under normal field conditions, oaks produce only one flush of growth and surmised that rapid growth of oak seedlings depends on multiple growth flushes within a single growing season. He also concluded that more information was needed on factors that control recurrent flushing so that conditions could be influenced or manipulated to encourage multiple growth flushes. Nutrient availability, particularly N, appears to be one of those controlling factors, and fertilization may be one way to influence site conditions to promote multiple growth flushes.

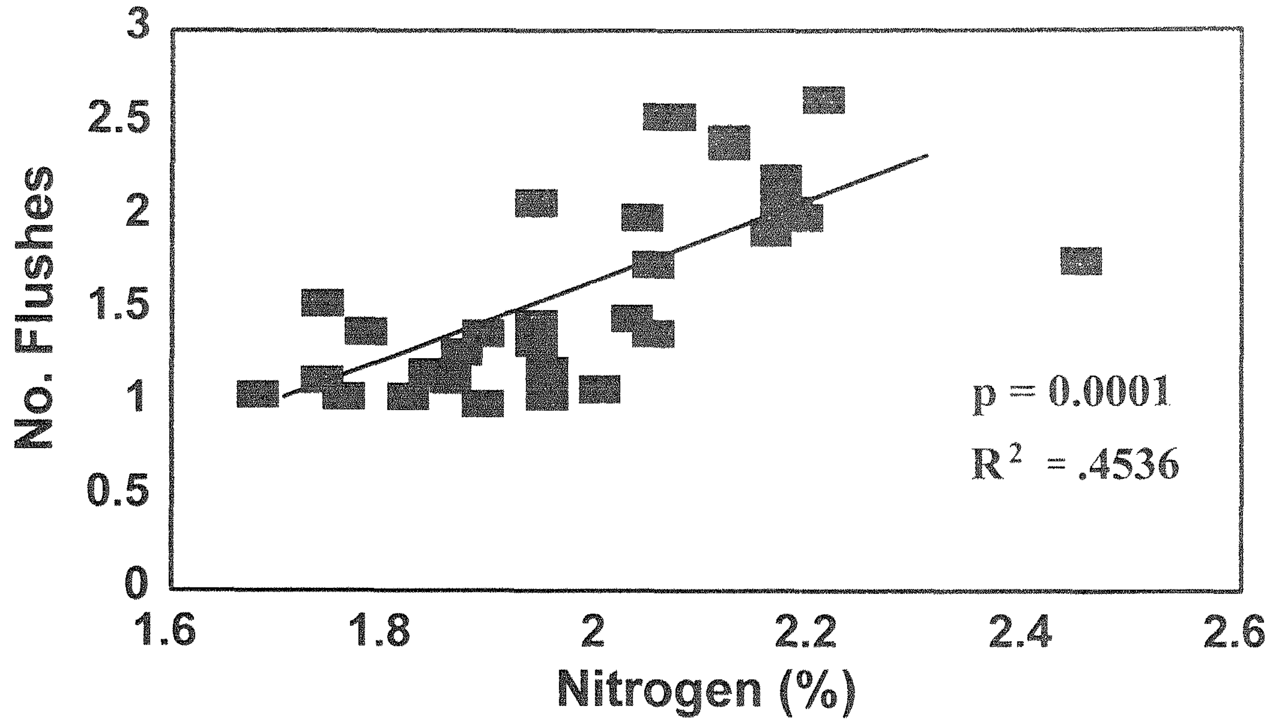


Figure 5. Number of growth flushes in the first year as a function of foliage N concentration for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

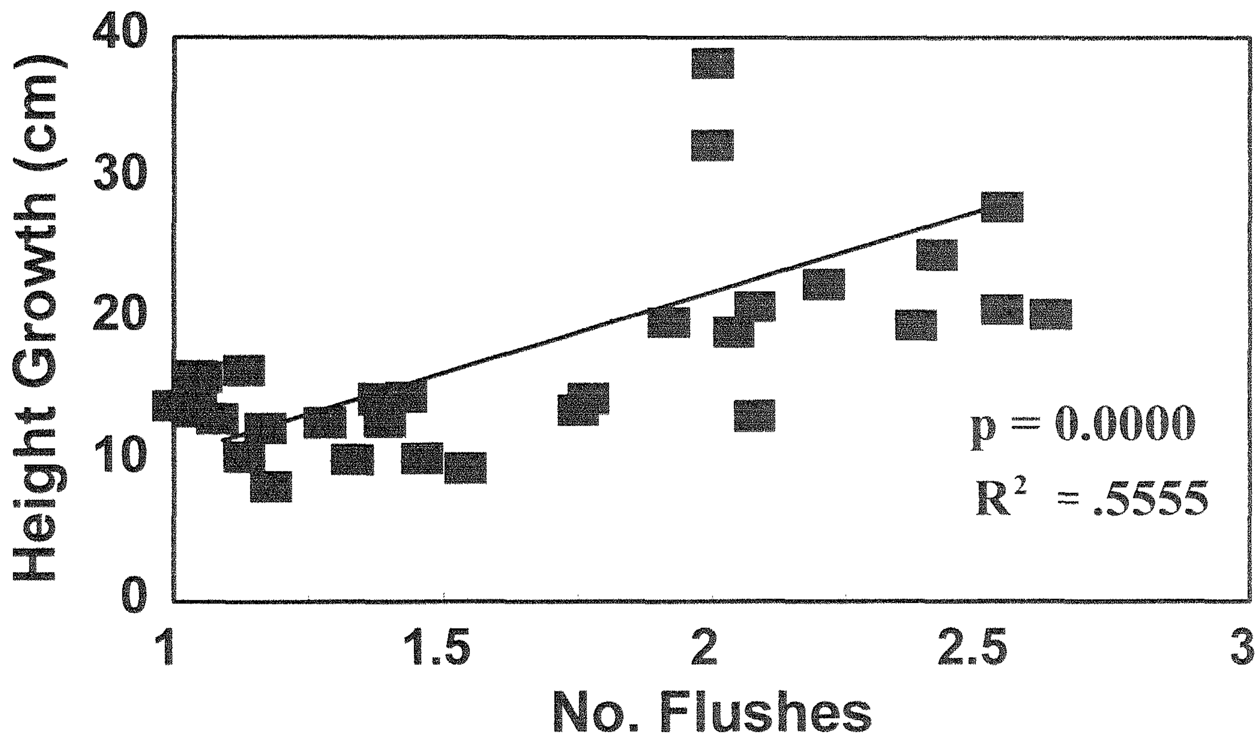


Figure 6. First-year height growth as a function of the number of growth flushes for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

CONCLUSIONS

The use of larger or graded planting stock significantly improves early northern red oak seedling establishment and growth. This study, along with many other studies show the importance of either growing larger stock in the nursery or culling or grading stock prior to planting.

Subsoiling improved rooting depth but no other root or stem parameters in the first growing season. Fracturing the subsoil horizon and allowing deeper root penetration at an early stage may have been more critical in a normal- or below normal- precipitation year. Tilling did not improve root growth and, with the exception of total shoot biomass, did not improve height or diameter growth. Tilling actually reduced the number of flushes in the first growing season presumably because of the more exposed condition it created for the seedlings.

Soil fertility was the most limiting factor on this site and is probably limiting on many other similar old field sites throughout the region. A high rate of N fertilization increased height growth, diameter growth, and total root biomass without altering root:shoot ratios. An increase in height growth was accomplished primarily by increasing the number of growth flushes. Fertilization of hardwood plantations in the Central Hardwood Region is not commonly practiced and rarely even considered as a viable silvicultural tool. Many hardwood plantings are made on recently row-cropped soils where tree seedlings benefit greatly from residual soil fertility. Although the results of this study are preliminary, old field sites or other low-fertility sites may be likely candidates for fertilizer applications to improve early oak establishment and growth. Treatment effects will be monitored through the establishment phase of the plantation.

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AN EIGHT-ACRE BLACK WALNUT PLANTATION:

HISTORY AND OBSERVATIONS 1982 - 1994

Charles J. Saboites[1]

Abstract: In 1982 a black walnut (*Juglans nigra*) plantation was partly established by planting 200 1-0 seedlings on the first bench adjacent to Copper Creek near its mouth draining into the Clinch River, Scott County, Virginia. In the following years, 50-500 1-0 black walnut seedlings, supplemented by transplanting germinated nuts in failed spots, were planted on the first and second benches until a total of approximately 1600 were established through 1990.

Deer, rabbits, ground hogs, mice, fusarium and herbicide drift from a 175-foot tall railroad trestle all affected the growth of the seedlings as recorded in a diary kept by the author to back up tax credits and amortization claims under the 1980 Federal Reforestation Act.

Site preparation was done by chain saw, hand tools, hack and squirt method and with the use of a propane soldering torch.

The average diameter at breast height and the average height of selected 1-0 pruned crop trees planted in 1982, 1983, 1985 and 1986 were 6.16, 4.30, 3.40 and 3.66 inches and 32.59, 23.19, 19.78, and 18.78 feet respectively in the fall of 1994.

The paper is specific as to feelings of failure, success and experiences in establishing the plantation.

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DEVELOPMENT AND QUALITY OF REPRODUCTION IN TWO-AGE CENTRAL APPALACHIAN HARDWOODS -- 10-YEAR RESULTS

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Abstract: Silvicultural practices that promote two-age stand structures have the potential to meet a wide range of forest resource goals. Such practices can overcome perceived disadvantages associated with clearcutting and still provide sustainable yields of desirable timber products and other woodland benefits. Forest managers need information on stand development following two-age harvests to develop prescriptions that meet diverse landowner objectives over long planning periods. Species composition, distribution, and stem quality of commercial hardwood reproduction were evaluated in four central Appalachian hardwood stands 10 years after a two-age regeneration harvest. Regeneration harvests cut all stems 1.0 inch d.b.h. and larger except for 12 to 15 codominant residual trees/acre comprising 17 to 25 ft^2 basal area/acre. After 10 years, codominants in the regenerated stand exhibited similar species composition, abundance, distribution, stem size, and quality as that previously reported for clearcuts in similar stands. Competition from the much taller residual trees in the older age class apparently has no effect on the 10-year development of the new age class. Forest managers can use the information provided to determine if two-age silvicultural practices applied in similar stands have the potential to meet specific stand management goals.

INTRODUCTION

Two-age management in central Appalachian hardwoods has the potential to provide a variety of aesthetic, habitat, and timber production benefits that may satisfy a wide range of land management objectives. Such practices involve leaving 15 to 20 codominant residual trees per acre, and perhaps some flowering shrubs or den trees for aesthetics and wildlife, and cutting all other stems 1.0 inch diameter breast height (d.b.h.) and larger. After cutting, two-age stands initially resemble those following a seed-tree cut. However, in two-age stands the codominant residual trees are retained for many years, often as long as a second rotation. The presence of a few codominant residual trees greatly improves aesthetics compared to that in clearcut stands (Figure 1).

Light conditions on the forest floor following a two-age cut are similar to those expected after traditional clearcutting or seed-tree practices, and result in regeneration of a variety of both shade-intolerant and shade-tolerant species (Smith and others 1989). As new reproduction becomes established and grows beneath the residuals, the vertical structure of the stand includes two distinct height strata. These strata provide a diverse habitat, particularly for migratory bird species that forage among the crowns of mature hardwoods (Nichols and Wood 1995). A brushy cover characteristic of young even-aged stands is present for many years, thus providing cover and food for a variety of wildlife species.

Logging operations in second-growth hardwoods to develop two-age stand structures are economical in most Appalachian markets (Miller and Baumgras 1994). To maintain a two-age stand structure, regeneration harvests are conducted at minimum intervals equal to one-half the length of a typical even-age rotation. In the central Appalachians, where economic rotations for sawtimber production are approximately 60 to 80 years, two-age harvests can be applied at least every 40 years. Preliminary results indicate that two-age regeneration practices can provide sustainable yields of desirable commercial timber products and other woodland benefits.

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Figure 1. A two-age central Appalachian hardwood stand 5 years after a regeneration harvest.

This report summarizes 10-year results on the quality and development of natural regeneration resulting from two-age harvests in four central Appalachian hardwood stands. Although diameter growth of the residual codominant trees is stimulated by removal of surrounding competitors, height growth of mature residual trees increases very little (Smith and Miller 1991). Similar to even-age stands, a new age class becomes established and grows rapidly in both total height and d.b.h. for many years. An earlier report described the application methods and summarized preliminary 5-year results for two stands (Smith and others 1989).

STUDY AREAS

Four study areas were established in cooperation with the Monongahela National Forest on two ranger districts and on the Fernow Experimental Forest in north-central West Virginia. Stand size ranged from 10.2 to 14.8 acres. Two stands were located on each of two northern red oak site classes, site index (SI) 70 and 80 at base age 50 years. The stands were uncut, second-growth central Appalachian hardwoods with an average age of about 75 years that became established after heavy logging in the early 1900's. Periodic fire was common throughout the study area as the stands became established, though no fires have occurred in these areas in the last 50 years. Chestnut blight also killed some large trees during the 1930's and resulted in patchy reproduction before and during World War II.

In general, soils on the study areas are medium-textured and well-drained, derived from sandstone shale with occasional limestone influence. The average soil depth in the general area exceeds 3 feet. However, the Olson Tower stand is on a Cookport silt loam soil with a fragipan at a depth of about 20 inches, resulting in shallow-rooted trees and problems with soil compaction on skid trails and log landings. Annual precipitation averages 59 inches and is well distributed throughout the year. The growing season averages 145 frost-free days.

METHODS

Regeneration harvests were applied in the four stands by retaining 12 to 15 codominant trees per acre and cutting all other stems 1.0 inch d.b.h. and larger (Table 1). In selecting the residual trees, the goal was to leave a residual basal area of approximately 20 ft^2/acre. Residual trees were selected using the following criteria:

Species -- northern red oak (*Quercus rubra* L.), yellow-poplar (*Liriodendron tulipifera* L), black cherry (*Prunus serotina* L.),
Crown class -- dominant or codominant,
Vigor -- no evidence of epicormic branches or other sign of decline,
Risk -- no disease, low forks, shallow roots, or other risk factors,
Quality -- current or potential high-quality butt log, and
Spacing -- residual trees well distributed throughout the stand.

Logging operations to remove merchantable sawtimber (11.0 inches d.b.h. and larger) were conducted between 1980 and 1983. Nonmerchantable stems were felled and left on the site. A truck-crane cable system was used to log the Fish Trough stand and a portion of the Shavers Fork stand. Wheeled skidders were used in the Riffle Creek and Olson Tower stands, and the remaining portion of the Shavers Fork stand.

Reproduction data were obtained before logging, and at 2, 5, and 10 years after logging from 172 permanent sample points located along systematic grids throughout the four study areas. At each point, a 1/1000-acre and 1/100-acre circular plot were used to sample small and large reproduction, respectively. Small reproduction was defined as woody stems at least 1 foot tall and less than 1.0 inch d.b.h. Large reproduction was defined as woody stems 1.0 inch d.b.h. and larger. Species, d.b.h., stem origin, quality, and crown class were recorded for each tree observed on a plot. Tree quality was based on the potential of individual trees to become sawtimber crop trees in the future. Trees with straight, clean boles, well-developed crowns, and no evidence of potential problems were classified as good. Trees with low forks, crooked or leaning stems, or evidence of low vigor were classified as poor.

RESULTS

Before harvest, small reproduction varied in terms of species composition and total number of stems per acre among the four stands (Table 2). On SI 70, shade-tolerant species such as sugar maple (*Acer saccharum* **Marsh.**), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* **Ehrh.**) accounted for 79 percent of small reproduction in

Table 1.--Summary per-acre data for four central Appalachian hardwood stands before and after a two-age regeneration harvest

Stand	Number of trees		Basal area		Volume			Average d.b.h.	
	5.0-10.9	11.0+	5.0-10.9	11.0+	5.0-10.9	11.0+	11.0+	5.0-10.9	11.0+
	---- No./acre ----		---- ft^2/acre ----		---- ft^3/acre ----		Mbf/acre[a]	----- Inches ----	
				SI 70					
Riffle Creek - 14.8 acres									
Initial	120.2	68.6	41.3	87.7	741	2,202	12,932	7.9	15.3
Cut	118.9	57.4	40.6	70.9	727	1,773	10,305	7.9	15.0
Residual	1.3	11.2	0.7	16.8	14	429	2,627	9.9	16.6
Olson Tower - 12.1 acres									
Initial	100.5	79.9	30.4	102.9	519	2,593	15,721	7.4	15.4
Cut	99.2	65.9	29.7	84.9	505	2,138	12,987	7.4	15.4
Residual	1.3	14.0	0.7	18.0	14	455	2,734	9.9	15.4
				SI 80					
Fish Trough - 13.1 acres									
Initial	48.9	72.2	16.5	112.7	316	3,058	20,630	7.9	16.9
Cut	48.7	58.1	16.4	88.0	314	2,379	15,697	7.9	16.7
Residual	0.2	14.1	0.1	24.7	2	679	4,933	9.6	17.9
Shavers Fork - 10.2 acres									
Initial	110.6	63.4	34.1	81.9	626	2,175	14,221	7.5	15.4
Cut	110.2	50.7	33.9	61.8	621	1,627	10,363	7.5	15.0
Residual	0.4	12.7	0.2	20.1	5	548	3,858	9.6	17.0

[a]International 1/4-inch rule.

the Riffle Creek stand, and shade-intolerant black cherry accounted for 87 percent of small reproduction in the Olson Tower stand. On SI 80, small reproduction in the Fish Trough stand was mostly sugar maple and American beech (84 percent), and mostly American beech and white ash (*Fraxinus americana* L.) (74 percent) in the Shavers Fork stand.

The distribution of small reproduction before harvest was typical of second-growth central Appalachian hardwood stands on good growing sites (Trimble 1973). In general, more than 80 percent of the survey plots had at least one seedling or sprout of a commercial species present. For the Olson Tower stand, 69 percent of the survey plots had at least one black cherry stem present before harvest. For the other stands, more than 60 percent of the survey plots had at least one sugar maple or American beech seedling present before harvest.

Table 2.--Summary of small reproduction[a] of commercial species before and 2 years after a two-age regeneration harvest

Before cut		After 2 years		Before cut		After 2 years	
Species	No./acre	Species	No./acre	Species	No./acre	Species	No./acre
SI 70							
Riffle Creek				Olson Tower			
Beech	1,575	Red maple	1,170	Bl. cherry	4,311	Bl. cherry	9,600
S. maple	745	Beech	1,170	Beech	467	Beech	844
Red maple	340	Ch. oak	957	Basswood	67	R. maple	689
Red oak	255	S. maple	532	Others	112	S. maple	200
Bl. cherry	128	Red oak	489	--	--	Bl. birch	178
White oak[b]	128	Bl. cherry	298	--	--	Red oak	44
Ch. oak	106	Sassafras	234	--	--	Others	133
Others	105	White ash	128	--	--	--	--
--	--	Others	64	--	--	--	--
Total	3,382	Total	5,042	Total	4,957	Total	11,688
SI 80							
Fish Trough				Shavers Fork			
S. maple	833	S. maple	2,033	Beech	1,200	Y-poplar	3,600
Beech	300	Y-poplar	1,733	White ash	520	Beech	2,300
Wh. ash	167	Beech	1,433	S.maple	380	Red oak	2,000
Others	116	Sw. birch	467	Red oak	40	White ash	1,640
--	--	Bl. cherry	433	Others	180	S.maple	700
--	--	Elm	167	--	--	Bl. cherry	220
--	--	Others	100	--	--	Others	1,800
Total	1,416	Total	6,366	Total	2,320	Total	12,260

[a]Small reproduction includes woody commercial species 1.0 feet tall to 0.9 inches d.b.h.
[b](*Quercus alba* L.).

Two years after harvest, small reproduction in the study areas averaged 9,100 commercial stems per acre composed of 60 percent seedling-origin stems (Table 2). On SI 70, red maple, American beech, black cherry, and sugar maple were the most abundant species. Yellow-poplar, American beech, and sugar maple were the most abundant species on SI 80. In the Riffle Creek and Shavers Fork stands, there were 489 (17 percent were sprouts) and 2,000 (65 percent were sprouts) northern red oak stems per acre, respectively (Table 2). Some northern red oak was present in these stands before harvest.

Five years after harvest, the canopy of the new age class developing beneath the residual overstory trees had not closed. For large reproduction 1.0 inch d.b.h. and larger, species composition and number of stems per acre varied among the four stands (Table 3). In the Olson Tower stand, reproduction was dominated by black cherry, averaging 200 stems per acre. The Riffle Creek stand also had more than 200 stems per acre, distributed among a variety of species including chestnut oak (*Quercus prinus* L.), red maple, yellow-poplar, northern red oak, and American beech. Large reproduction in stands on the more productive sites was dominated by yellow-poplar, basswood (*Tilia americana* L.), cucumbertree (*Magnolia acuminata* L.), and sugar maple. The Shavers Fork stand had more than 350 yellow-poplar stems per acre, mostly of seedling origin.

Table 3.--Summary of large reproduction[a] of commercial species 5 years and 10 years after a two-age regeneration harvest

After 5 years		After 10 years		After 5 years		After 10 years	
Species	No/acre	Species	No/acre	Species	No/acre	Species	No/acre
SI 70							
Riffle Creek				Olson Tower			
Ch. oak	62	Beech	179 (51)[b]	Bl. cherry	200	Bl. cherry	744 (130)
Red maple	53	Bl. birch	145 (36)	Others	18	Red maple	71 (25)
Y-poplar	43	Red maple	138 (32)	--	--	Red oak	42 (20)
Red oak	26	Red oak	128 (31)	--	--	Beech	38 (10)
Beech	15	Ch. oak	96 (31)	--	--	Others	38 (12)
Others	41	Sug. maple	89 (27)	--	--	--	--
--	--	Y-poplar	87 (40)	--	--	--	--
--	--	Bl. cherry	55 (20)	--	--	--	--
--	--	Others	145 (41)	--	--	--	--
Total	240	Total	1,062 (94)	Total	218		933 (130)
SI 80							
Fish Trough				Shavers Fork			
Basswood	70	Y-poplar	310 (88)	Y-poplar	352	Y-poplar	434 (72)
Sugar maple	57	Sug. maple	273 (70)	Cucumber	53	Beech	94 (19)
Y-poplar	33	Bl. birch	103 (39)	Sug. maple	16	Bl. birch	74 (17)
Other	70	Basswood	93 (74)	Red maple	16	Red maple	64 (28)
--	--	Others	221 (53)	Others	57	Sug. maple	54 (16)
--	--	--	--	--	--	Red oak	44 (16)
--	--	--	--	--	--	Others	208 (41)
Total	230	Total	1,000 (117)	Total	494	Total	972 (89)

[a] Large reproduction includes woody commercial species 1.0 inches d.b.h. and larger.
[b] Standard error of estimated mean.

Ten years after harvest, the abundance of large reproduction under the residual overstory trees was uniform among the four study areas averaging more than 990 stems per acre. Although not present in large numbers at 5 years, black birch (*Betula lenta* L.) had become a notable competitor in three stands 10 years after treatment (Table 3). For stands on SI 70, black cherry, American beech, red maple, black birch, and northern red oak were the predominant species. On SI 80, yellow-poplar, sugar maple, red maple, and black birch were predominant species. In an earlier study of regeneration resulting from the seed-tree method, stands on site indices 70 and 80 had more than 1,200 and 1,700 stems per acre, respectively, 12 years after harvest (Smith and others 1976). Data from the two-age stands reported here indicate that stand development is similar to that observed for even-age practices where overstory trees are removed during or soon after the regeneration harvest.

Codominant stems present at the time of crown closure have an important impact on species composition and quality of future crop trees developing in the new age class. In general, crown closure among the new age class was nearly complete at 10 years, though the Olson Tower stand had patchy areas where reproduction was lacking due to soil compaction. On SI 70, the Riffle Creek and Olson Tower stands averaged about 700 codominant commercial stems per acre 10 years after two-age harvests were applied (Table 4). More than 70 percent of the codominant stems were classified as good quality with the potential to become crop trees in the future (Figure 2). While the number and quality of codominant stems was similar for the two stands on SI 70, species composition was more variable in the Riffle Creek stand. On SI 80, the Fish Trough and Shavers Fork stands averaged 493 codominant stems per acre with more than 85 percent classified as good quality with the potential to become crop trees in the future. Species composition of good, codominant stems was similar in these two stands. Yellow-poplar, black birch, sugar maple, and cucumber were the predominant species 10 years after harvest.

In general, approximately one-half of the commercial reproduction in a codominant crown position after 10 years originated as seedlings among the four study areas (Table 4). Sprout-origin stems accounted for 62 percent of codominant stems in the Shavers Fork stand where yellow-poplar was most abundant. The Olson Tower stand, dominated by black cherry, had only 37 percent sprout-origin stems.

Table 4.--Summary of codominant commercial stems 10 years after a two-age harvest

Stand	Site index	Codominants	Sprout-origin codominants	Sprouts
		------- No. stems/acre	-------	--- Percent ---
Riffle Creek	70	612	308	50
Olson Tower	70	735	276	37
Fish Trough	80	486	203	42
Shavers Fork	80	458	284	62

Height growth of codominant reproduction in the two-age stands was also similar to that observed in even-aged stands in the study area . Height of reproduction in the two-aged stands was measured in 1994, when new reproduction in the study stands ranged from 11 to 15 years old (Table 5). Total height of reproduction in the Olson Tower stand averaged 29 feet and was based on 11-year-old seedling-origin black cherry. Codominant reproduction in the remaining stands had reached 40 feet tall by age 15. By comparison, seedling-origin yellow-poplar and black cherry stems averaged 30 to 35 feet tall (Lamson and Smith 1989), and sprout origin yellow-poplar, black cherry, red maple, and red oak averaged 37 feet tall (Lamson 1983) in 12-year-old clearcuts on SI 70.

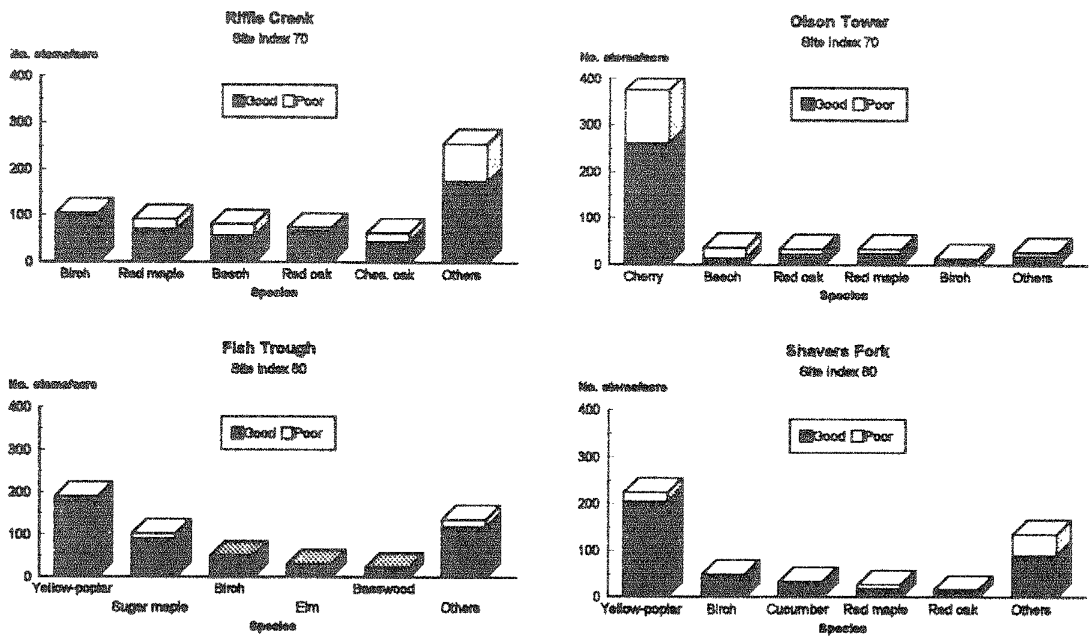

Figure 2. Distribution of codominant reproduction by stand and stem quality 10 years after a two-age harvest .

Table 5.--Average total height of codominant reproduction in two-age central Appalachian hardwood stands

Stand	Site index[a]	Age	Total height
		Years	Feet
Riffle Creek	70	15	42
Olson Tower	70	11	29
Fish Trough	80	14	42
Shavers Fork	80	13	40

[a]Northern red oak site index base age 50 years.

DISCUSSION

Similar to reproduction following clearcutting, the two-age regeneration harvest as applied in this study promoted the development of a variety of commercial hardwood species. For the new age class developing beneath the larger trees, light conditions were suitable for the development of desirable shade-intolerant and shade-tolerant species. In general, yellow-poplar, black cherry, black birch, sugar maple, red maple, and American beech were the most abundant species in a codominant crown position after 10 years. Some good quality, codominant northern red oak stems also were present, though the stands on SI 80 averaged less than 10 stems per acre.

At low residual stocking levels similar to the study stands, reproduction in the new age class can be expected to continue to develop without competition from the larger overstory trees for many years. The residual basal area in 12 to 15 overstory trees/acre ranged from 17.5 to 25.8 ft^2/acre in the four stands reported here. After 10 years, the crowns of residual overstory trees were still widely spaced with approximately 20 feet of growing space between adjacent trees. Crown expansion among the overstory residual trees was negligible after 10 years, and reproduction in the new age class should have ample growing space to allow shade-intolerant species to reach merchantable size classes in the future.

Large reproduction (1.0 inch d.b.h. and larger) also included noncommercial species such as serviceberry (*Amelanchier arborea* **(Michx. f.) Fern.**), striped maple (*Acer pensylvanicum* L.), pin cherry (*Prunus pensylvanica* L. f.), flowering dogwood (*Cornus florida* L.), and American hornbeam (*Carpinus caroliniana* **Walt.**) 10 years after harvest. On SI 70, noncommercial reproduction averaged 250 stems per acre with 160 stems per acre in a codominant crown position. On SI 80 stands, noncommercial reproduction averaged 340 stems per acre, with 96 stems per acre in a codominant crown position. Although noncommercial species can inhibit the growth of neighboring timber crop trees, they do provide food and cover for wildlife and some have showy flowers that enhance the aesthetics of two-age stands in the spring. However, data from this study indicate that an adequate number of timber crop trees can develop in the presence of noncommercial hardwoods.

Similar to even-age practices, light conditions following a two-age regeneration cut enhance the development of wild grapevines on good growing sites. In an earlier study of even-aged stands, grapevines were found growing in 48 to 74 percent of trees 1.0 inch d.b.h. and larger after 12 growing seasons (Smith and others 1976). Although some vines are beneficial to wildlife, stem quality and growth of commercial trees can be reduced when too many vines are present. Vines matted in trees result in crown damage by ice and snow storms in the dormant season, and slow growth because of shading during the growing season. In this study, wild grapevines (*Vitus* **spp.**) were present in all stands 10 years after harvest. In the Shavers Fork stand, 58 percent of commercial trees had at least one vine in the crown. The Riffle Creek and Fish Trough stands each had 25 percent, and the Olson Tower stand had less than 1 percent of commercial trees with vines. Grapevines were cut at ground line after 10 growing seasons to control spreading. This operation required 0.8 to 1.8 man-hours/acre to cut from 70 to 270 vines/acre, respectively.

Residual overstory trees in the four study areas are scheduled for another two-age harvest when the new age class is 80 years old. At that time, the two-age harvest method will be applied again, leaving 12 to 15 trees per acre from the new age class, and cutting all other trees 1.0 inch d.b.h. and larger. To improve the composition, spacing, and quality of the new age class, some potential crop trees in the 10-year-old age class should be released using a crown-touching technique (Lamson and Smith 1989). Such early cultural treatments will improve the value and marketability of two-age harvests in the future.

SUMMARY

The development and quality of natural hardwood reproduction following a two-age regeneration harvest can be summarized by several key observations.

- Leaving 12 to 15 residual overstory trees per acre and cutting all other trees 1.0 inch d.b.h. and larger resulted in hardwood reproduction similar to that expected after clearcutting.
- Two years after harvest, small reproduction (1.0 foot tall to 0.9 inch d.b.h.) averaged 9,100 commercial hardwood stems per acre, composed of 60 percent seedling-origin stems.
- Five years after harvest, large reproduction (1.0 inch d.b.h. and larger) averaged more than 300 commercial hardwood stems per acre, and the canopy had not closed.
- Ten years after harvest, large reproduction averaged 990 commercial hardwood stems per acre, with 574 stems per acre (58 percent) in a codominant crown position.
- Codominant trees averaged 30 to 40 feet tall after 10 growing seasons, and the canopy of the new age class was nearly closed.
- From 70 to 85 percent of codominant reproduction after 10 growing seasons was considered good quality with the potential to become timber crop trees.
- Ten years after harvest, species composition of the new age class was variable, including shade-intolerant species such as yellow-poplar, black cherry, northern red oak, chestnut oak, and black birch, and shade-tolerant species such as American beech, red maple, and sugar maple.
- Large reproduction in a codominant crown position also included serviceberry, striped maple, pin cherry, flowering dogwood, and American hornbeam.
- After 10 growing seasons, residual overstory trees left to form the older age class were still free-to-grow, with an average of 20 feet of growing space between adjacent crowns.
- Reproduction in the new age class is expected to develop for many years without serious competition from the residual overstory trees.

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SHELTERWOOD TREATMENTS FAIL TO ESTABLISH OAK REPRODUCTION ON MESIC FOREST SITES IN WEST VIRGINIA--10-YEAR RESULTS

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Abstract: The difficulty in regenerating oak on mesic forest sites is well known throughout the eastern and central United States, southern Ontario and Quebec, Canada. Research has shown that the establishment and development of oak seedlings prior to overstory removal, commonly referred to as advanced regeneration, is crucial for retaining oak species in the regenerated stand. The shelterwood reproduction method has been suggested as a means of developing the advance regeneration needed. In 1983, various shelterwood treatments were evaluated on the Fernow Experimental Forest in north-central West Virginia. Three overstory and two understory densities resulting in six treatment combinations were studied. Advanced red oak (*Quercus rubra*) regeneration was not abundant before treatment over most of the study area. Both natural regeneration and planted northern red oak and white ash (*Fraxinus americana*) seedlings were evaluated. Growth of planted seedlings was not significant after 5 years, though survival of red oak was improved significantly by both overstory and understory treatments. Natural regeneration of red oak was inadequate to recommend further overstory removal, and did not differ significantly by treatment combination. Overstory treatments stimulated abundant sweet birch (*Betula lenta*) regeneration, reducing the chances of establishing oak in the future. These results suggest that forest managers in the central Appalachian region may be unable to establish or develop advance regeneration of sufficient size and quantity when attempting to regenerate oaks on mesic sites with the shelterwood method as implemented here.

INTRODUCTION

The difficulty in regenerating northern red oak (*Quercus rubra*) on mesic sites is well known throughout the eastern and central United States and southern Ontario and Quebec, Canada (Smith 1993a; Wagner 1993). Early logging activities that cleared much of the old-growth deciduous forests throughout the range often were heavy but variable, and largely a function of local markets, terrain, and logging technology of the time. Yet, even with the variability of these harvests and a nearly total disregard for the regeneration potential of the stand, the oak component was largely retained in the newly established stands. More recently, retaining oak on these same sites following a regeneration cut has proven most difficult. A continuation of current management practices likely will result in a widespread reduction of oak on mesic sites throughout the region. Fewer oak trees on these sites could have far reaching economic and ecological consequences.

Research has shown that successful regeneration of oak on mesic sites, site index 70 at 50 years or greater, requires the establishment and development of oak seedlings of sufficient size and number, often referred to as advanced regeneration, prior to overstory removal (Carvell and Tryon 1961; Loftis 1990a; Merritt 1979). Variations of the shelterwood regeneration method have been suggested as a means of developing the advanced regeneration needed, and preliminary results where oak seedlings are present have been encouraging (Loftis 1990b; Schlesinger and others 1993).

Oak regeneration can be broken down into three components: establishment, development, and growth after overstory removal. Establishment refers to the germination of acorns and persistence of new seedlings. Development is the

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increase in height and basal diameter before overstory removal. Growth after overstory removal refers to the probability of advance regeneration maintaining a competitive position in the new stand.

The objective of this study was to determine the effect of several shelterwood treatments on the establishment and development of new oak seedlings before final overstory removal. Because oak seedlings were not abundant on most of the study areas, treatments were intended to "establish" new regeneration. The study design allowed us to test the hypothesis that stocking from overstory and understory components is the principal constraint to the establishment and development of oak seedlings. Manipulating overstory and understory density by the use of cutting and herbicides, enabled us to evaluate the effects of several levels of stocking on oak-seedling dynamics.

METHODS

This study was established on the Fernow Experimental Forest (39.03° N, 79.67° W), near Parsons, West Virginia, during the 1983-84 dormant season. Mean annual precipitation on the Fernow is about 58 inches and is distributed evenly throughout the year. Mean annual temperature is 48° F and the length of the frost-free season is approximately 145 days. The elevation of the study sites ranges from about 2,400 to 2,600 feet. The soils within the study sites are characterized by a Calvin channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) that developed on uplands in material weathered from sandstone and shale. The Calvin soils are well drained and strongly acid, moderately deep, and moderately permeable. The site index for the study area is about 70 for northern red oak. Overstory species in the study area included northern red oak, chestnut oak (*Q. prinus*), and white oak (*Q. alba*) in descending order of dominance as measured by basal area. Other overstory species included red maple (*Acer rubrum*), sugar maple (*A. saccharum*), sweet birch (*Betula lenta*), and yellow-poplar (*Liriodendron tulipifera*). The study area is part of the Allegheny Mountains Section of the Central Appalachian Broadleaf Forest (McNab and Avers 1994).

The study design was implemented as a 2 x 3 factorial with three overstory treatments combined with two understory treatments for a total of six distinct shelterwood/herbicide treatments with two replications on 12 plots. An additional treatment with a 45-percent residual stocking was omitted from this analysis due to blowdown and salvage logging that occurred in those areas. All data were analyzed by analysis of variance using linear model procedures incorporating the factorial design and tested for significance at the 5-percent level unless otherwise noted. The Tukey-Kramer HSD was used for pairwise multiple comparisons; it is designed to maintain overall protection regardless of the number of comparisons.

The overstory treatments consisted of reducing residual stocking to 75 and 60 percent based on the upland-oak stocking guide (Gingrich 1967) plus an uncut control group (Fig. 1). Average stocking for all plots before treatment was 115 percent. All plots were marked for cutting by designating leave trees. Two guidelines were followed in selecting leave trees: 1) favor oaks for seed source purposes, and 2) achieve uniform spacing of residuals. Species and diameter at breast height (dbh) of each leave tree were tallied and stocking was calculated in the field. Trees less than 5.0 inches in dbh were ignored during marking even though they accounted for as much as 20 percent of stocking in some plots. Thus calculations of residual stocking level included only trees 5.0 inches and larger in dbh. In all plots except for the overstory control plots (no treatment), pole-size trees were either cut and removed, cut and left in place, or treated with herbicides.

The stocking guide for upland oak was selected for control of residual stocking to evaluate its suitability as a thinning guide in the central Appalachian region. The upland oak equations were based on more xeric site oaks such as white, black (*Q. velutina*), and scarlet (*Q. coccinea*), which tend to have smaller crowns relative to northern red oak. Thus, reductions to 75- and 60-percent residual stocking may be more severe than suggested by the residual stocking percentages. Residual stand structures are shown in Figure 2 for 75- and 60-percent residual stocking levels. Of the total number of stems after treatment, 71 and 83 percent were in oak species in the 75-percent and 60-percent residual stocking plots, respectively. Oak stems in both areas averaged 36 percent before treatment.

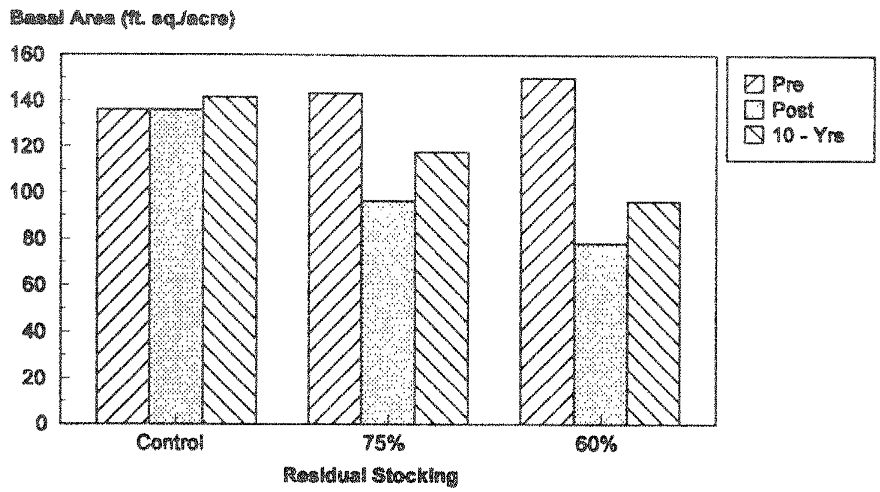

Figure 1. Average basal area per acre of trees 5.0 inches or larger in dbh before treatment (Pre), immediately after treatment (Post), and after 10 growing seasons (10-Yrs).

The understory treatments consisted of basal spraying a 2-percent solution of triclopyr (Garlon® 4) in oil on all stems less than 5.0 inches in dbh, plus an untreated control group. The herbicide treatment was designed to eliminate competition from existing shade-tolerant understory saplings, primarily striped maple and beech. This treatment was applied to two of the four replications for each overstory treatment.

Each treatment area was approximately 3 acres in size with a 0.5-acre growth plot in the center of the treatment area. Within each growth plot, all stems 5.0 inches and larger in dbh were permanently tagged (Lamson and Rosier 1984). Both small and large reproduction data were sampled. Data for small reproduction included the species, height class, and frequency of all woody vegetation observed within 20 0.001-acre sampling points distributed systematically in each plot. Sampling points were permanently marked. Height classes were defined as 0 to 6, 6 to 12, 12 to 36, 36 to 60, and more than 60 inches in total height but less than 0.99 inch in dbh. The results reported here focus on the establishment of seedlings larger than 1 foot tall due to an assumed ephemeral nature of smaller reproduction. Large reproduction was defined as woody species 1.0 to 4.9 inches in dbh observed within 10 0.01-acre sampling points and included all commercial and noncommercial woody species. The same plot centers were used to sample small and large reproduction with every other plot center used for large reproduction. Thus, data on small reproduction were obtained from 240 0.001-acre plots and large reproduction data were obtained from 120 0.01-acre plots.

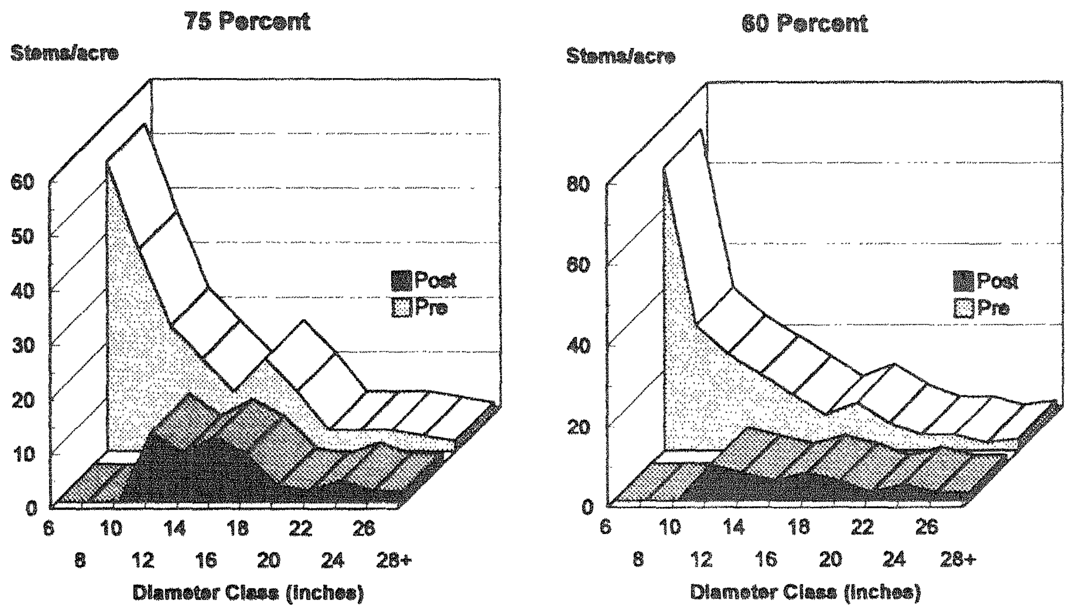

Figure 2. Characteristics of stand structure before treatment (Pre) and immediately after treatment (Post) for 75-percent and 60-percent residual stocking treatments.

All residual overstory trees were remeasured at the same interval as for the understory data. Reproduction plots and 0.5-acre growth plots were surveyed before and after logging prior to the first growing season and again 5, 7, and 10 years later. The most recent remeasurement was in the spring of 1994. During September 1991, near the completion of the eighth growing season, all of the treatment areas that received an initial understory herbicide treatment were mistblown with a 1-percent solution of glyphosate (Roundup®) herbicide. In 1991, understory vegetation ranged from 4 to 15 feet in height. Smaller red oak seedlings that germinated during the prior growing season were abundant when the understory was mistblown. The treatment was applied with backpack sprayers in such a way as to control undesirable vegetation without killing a significant portion of the red oak regeneration. Small-scale trials showed that this was achieved when glyphosate applied at a 45-degree upright angle and care was taken to avoid spraying the small desired vegetation.

In an attempt to ensure some seedling establishment, 50 red oak (2-0) and 50 white ash (*Fraxinus americana*) (1-0) seedlings were underplanted in each treatment area in the spring of 1984 following dormant-season logging. Seedlings were planted 10 feet apart so that the planting locations did not interfere with the reproduction plots. Mortality of planted seedlings was high and all seedlings were replanted before the start of the second growing season.

RESULTS

Natural Seedlings

After 10 growing seasons, the establishment of northern red oak seedlings more than 1 foot tall was low and did not differ for the overstory or understory treatment combination (Table 1). Results from a repeated measures uninvariate analysis of variance combining the results after 5, 7, and 10 growing seasons were similar and, again, demonstrated no significant differences for overstory (P = 0.219) or understory (P = 0.426) treatments. The repeated measures analysis of variance did suggest some differences in the number of large red oak seedlings within treatments over time (P = 0.052). Before treatment, the total number of small red oak seedlings less than 1 foot tall averaged 1,154 per acre and did not differ significantly by treatment area. Thus, some regeneration was present that had the potential to respond to the treatments even in the absence of new seedlings becoming established from acorns. After 5 growing seasons, many of these small oak seedlings were recruited into larger size classes. However, remeasurements after both 7 and 10 growing seasons showed that the total number of oak seedlings more than 1.0 foot tall declined at each measurement period. This decline coincided with increased competition from other species responding to the initial treatment (Fig. 3).

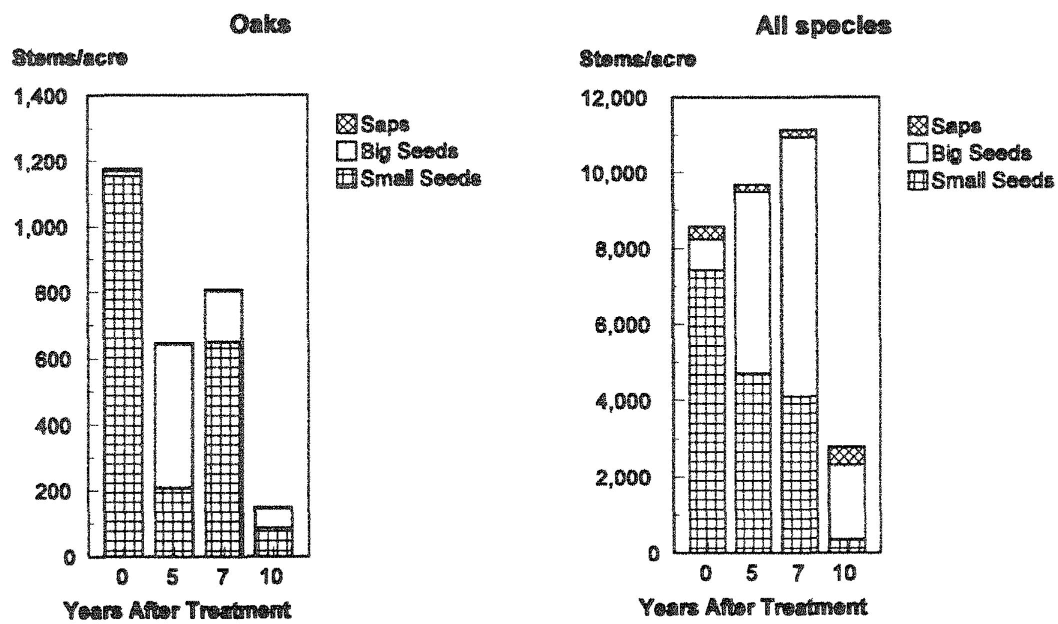

Figure 3. Characteristics of understory structure before the first growing season and 5, 7, and 10 years after treatment for oak and all species combined; "Saps" refers to trees 1.0 to 4.9 inches in dbh; "Big Seeds" includes stems taller than 1 foot but less than 1 inch in dbh; and "Small Seeds" includes stems less than 1 foot tall.

Table 1.--Statistical summary for northern red oak seedlings more than 1.0 foot tall and less than 1 inch in dbh 10 growing seasons after initial shelterwood/herbicide treatment combinations; sources of variation are denoted as OTREAT for overstory treatment and UTREAT for understory treatment

Source	Sum-of-squares	DF	Mean-Square	F-ratio	P
OTREAT	51666.667	2	25833.333	1.192	0.366
UTREAT	20833.333	1	20833.333	0.962	0.365
OTREAT*UTREAT	71666.667	2	35833.333	1.654	0.268

For species other than red oak, the abundance and species composition of small reproduction differed among treatments after 10 years. Perhaps most striking was the response of sweet birch. Analysis of variance indicated that the number of sweet birch seedlings, which are intermediate in shade tolerance (Trimble 1975), were significantly different with respect to overstory (P = 0.045) but not to understory treatment (P = 0.129). There were no significant interactions between overstory and understory treatments (P = 0.342). When overstory treatment alone was the grouping variable, the 60-percent stocking plots were significantly different according to the Tukey-Kramer HSD pairwise comparison (Table 2). Graphically, it appears that the threshold conditions necessary for birch regeneration were reached at 75-percent overstory stocking in combination with understory removal (Fig. 4). At higher levels of residual stocking, including the 75 percent overstory with no understory treatment, birch is a minor component of the understory.

Table 2.--Average number of seedlings per acre (1.0 foot tall to 0.99 inch in dbh) by overstory/understory treatment combination 10 years after treatment (standard error of treatment mean in parentheses)

		Species Group					
Overstory treatment (percent)	Understory treatment	Striped maple	Other tolerant	Birch	Other intermediate	Intolerant	Total
60	Yes	1,750 (200)	350 (300)	1,825 (775)a	1925 (975)	1,475 (425)a	7,325 (125)a
60	No	3,375 (25)	150 (160)	1,025 (225)a	175 (175)	75 (75)b	4,800 (200)a
75	Yes	2,450 (450)	175 (175)	1,075 (425)b	175 (175)	325 (175)b	4,200 (1400)b
75	No	2,750 (600)	100 (0)	50 (0)b	175 (175)	25 (25)b	3,100 (750)b
100	Yes	2,875 (1025)	175 (25)	100 (100)b	100 (100)	25 (25)b	3,275 (975)b
100	No	2,750 (100)	175 (75)	250 (250)b	50 (50)	0 (0)b	3,225 (125)b

Note: Values in columns followed by the same letter are not significantly different at 5-percent level using Tukey-Kramer HSD.

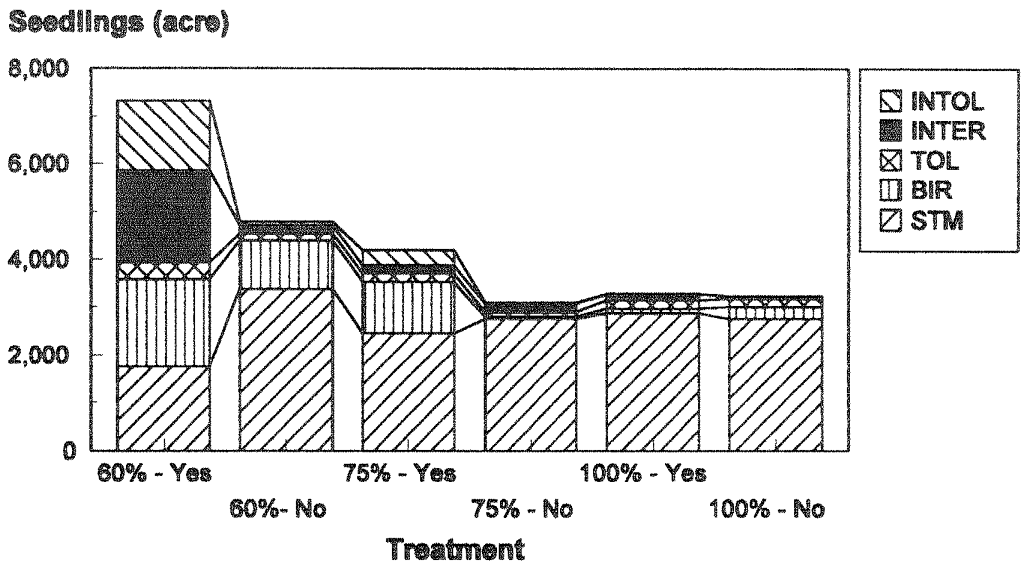

Figure 4. Number of stems per acre (1 foot tall to 0.99 inch in dbh) for each species group 10 years after treatment. "Yes" or "No" indicates understory treatment; species groups are striped maple (STM), sweet birch (BIR), shade-tolerant species excluding striped maple (TOL), intermediate shade-tolerant species excluding birch (INTER), and shade-intolerant species (INTOL).

Other intermediate shade-tolerant species demonstrated no significant differences among either overstory (P = 0.109) or understory treatments (P = 0.130). The small number of replications (n=2) and wide variability prevent a finding of significance, yet it appears that the combination of understory treatment and 60-percent residual overstory stocking promotes a variety of intermediate shade-tolerant species. This category included Fraser magnolia (*Magnolia fraseri*), cucumber (*Magnolia acuminata*), red oak, and white oak in descending order of abundance. The results also illustrate that these species are less shade tolerant than birch.

Intolerant species were significantly different among overstory (P=0.016) and understory (P=0.010) treatments. This was the only response variable that demonstrated significant differences for both types of treatments. However, only at the 60-percent residual stocking level in combination with understory removal were the intolerant species significantly more abundant. Species observed in this category included black cherry (*Prunus serotina*), yellow-poplar, sassafras (*Sassafras albidum*), and black locust (*Robinia pseudoacacia*).

Striped maple (*Acer pensylvanicum*) was isolated from other shade-tolerant species because of its relative abundance and influence on the regeneration of other species. Striped maple was abundant in all treatments, and not significantly related to overstory (P=0.880) or understory (P=0.212) treatments. The understory treatment designed to reduce competition, in part, from this noncommercial species was largely ineffective, possibly because seeds of striped maple ripen in September and October and are dispersed in October and November. The spring-applied triclopyr to existing stems did cause increased mortality of existing stems but did not negatively influence germination of striped maple from seed. The understory treatment may even have created conditions more suitable for survival of first year seedlings of striped maple whose seeds can remain viable for up to 2 years (Wilson and others 1979). Effective control of striped maple must include both existing stems and viable seed.

Other shade-tolerant species that were largely absent from the regeneration included red maple, sugar maple, American beech (*Fagus grandifolia*), eastern hophornbeam (*Ostrya virginiana*), black gum (*Nyssa sylvatica*), and eastern hemlock (*Tsuga canadensis*). This group did not exhibit differences for the overstory (P = 0.760) or understory treatment (P = 0.485).

The total number of all woody species combined was significantly different with respect to the overstory (P = 0.021) but not understory treatment (P = 0.099). However, from the results noted, the differences in this category are due primarily to differences in the number of intolerant and intermediate shade-tolerant species, including birch.

Analyzing the response to treatments was hindered by the confounding nature of the understory treatment applied at the end of the eighth growing season. This treatment was applied only on plots with an initial understory treatment, so we excluded all of these plots and repeated the analysis for overstory treatment only. Again, neither the response among overstory treatments (P=0.116) nor within treatments (P=0.256) was significant over time in a repeated measures design for large red oak seedlings.

In summary, the response to treatments can be characterized by an initial increase in red oak seedlings more than 1 foot tall at 5 years and a subsequent decline of the same due to an inability to maintain competitive positions with other species beyond 5 years. Greater reductions in basal area evoked greater response in recruitment of smaller oak seedlings into larger size classes, though the effect was ephemeral as the other faster growing species became established and surpassed oak seedling development in total height and competitive position. Beyond 7 years, recruitment of new individual stems greater than 1 foot tall has stopped and mortality within the new cohort began. Unless the small percentage of oak in the understory can become more dominate at a later stage of development, it would seem that the efforts to establish a new cohort of oak have been unsuccessful.

Planted Seedlings

Underplanted seedlings could serve as a source of regeneration if the seedlings respond to treatments. Survival of planted red oak seedlings was significantly different for both overstory (P = 0.004) and understory (P = 0.017) treatments. Survival was inversely related to percent stocking and further enhanced by understory removal. After 4 growing seasons, survival of red oak exceeded 90 percent for both the 60- and 75-percent stocking areas where the understory was removed (Table 3). Height growth of red oak was negligible and total height declined due to browsing by deer, and neither was significantly related to overstory (P = 0.065) or understory (P = 0.063) treatment.

Survival of white ash seedlings was not significantly related to overstory (P = 0.237) or understory (P = 0.438) treatment. Seedling total height was significantly related to overstory (P = 0.005) but not understory (P = 0.111) treatment. Both the 60- and 75-percent residual stocking treatments significantly increased height growth relative to no reduction in the overstory density. The practical significance of this may be minor as height growth averaged less than 1 foot in 5 years (Table 4). Further, survival of both species declined after 7 years, perhaps due to the reemergence of the treated understory. As a consequence, planted seedlings were not protected from the understory treatment that was applied at the end of eight growing seasons so survival rates after this period no longer can be considered valid.

Table 3.--Survival and height growth of planted northern red oak seedlings (2-0) 5 years after treatment (standard error of treatment means in parentheses)

Overstory treatment	Understory treatment	Number of seedlings	Initial height	5-year height	Survival
Percent			Feet	Feet	Percent
60	Yes	90	1.40	1.59 (.01)	90 (10)a
60	No	100	1.33	1.19 (.19)	65 (1)b
75	Yes	100	1.22	1.19 (.18)	91 (1)a
75	No	100	1.50	1.33 (.00)	50 (16)b
100	Yes	100	1.35	1.24 (.03)	32 (14)b
100	No	100	1.23	0.81 (.15)	20 (4)b

Note: Values in columns followed by the same letter are not significantly different at 5-percent level using Tukey-Kramer HSD.

Table 4.--Survival and height growth of planted white ash seedlings (1-0) 5 years after treatment (standard error of treatment means in parentheses)

Overstory treatment	Understory herbicide	Number of seedlings	Initial height	5-Year height	Survival
Percent			Feet	Feet	Percent
60	Yes	110	0.67	1.39 (.17)a	94 (4)
60	No	100	0.70	1.25 (.21)a	78 (6)
75	Yes	100	0.66	1.67 (.10)a	91 (3)
75	No	100	0.73	1.25 (.15)a	83 (1)
100	Yes	100	0.66	0.77 (.12)b	64 (26)
100	No	99	0.67	0.70 (.05)b	55 (29)

Note: Values in columns followed by the same letter are not significantly different at 5-percent level using Tukey-Kramer HSD.

DISCUSSION

The results of this study indicate that residual stocking levels alone may not affect the establishment of oak seedlings on mesic sites in the central Appalachian region. In fact, attempts to establish oak through partial overstory reductions could create conditions that favor the establishment of other species such as sweet birch that can regenerate well in partially shaded understories. Also, in this study, a range of conditions was created that favored the establishment of species from shade tolerant to shade intolerant. That red oak is classified as intermediate in shade tolerance demonstrates that while stocking and its influence on light reaching the forest floor may be a constraint to the establishment of red oak seedlings in some situations, there are other constraints that are even more limiting.

For the southern Appalachians, Loftis (1990b) cautioned that the goal of basal area reductions to regenerate oak on mesic sites should be to develop existing seedlings only. Our results clearly illustrate the basis for this warning. The greater the reduction in basal area, the greater the response by non-oak species to use that growing space. Others have suggested that competing non-oak species must be controlled with fire or herbicides to provide an opportunity for oak species to develop (Schlesinger and others 1993). However, understory treatments in this study were insufficient to retard the development of competing species.

Disturbance patterns in the presettlement forest that created conditions suitable for oak stands on mesic site may have differed greatly from existing patterns. For example, fires of varying intensity may have been much more common. Postfire mortality was highly correlated with tree size, fire severity, and species in Virginia 2 years after wildfire (Regelbrugge and Smith 1994). In the Virginia study, the relative basal area of chestnut oak increased following severe fires, indicating characteristics of species-specific fire resistance. In the Fernow study, birch quickly became established in the understory following reductions in basal area , apparently preventing further recruitment by other species. Yet birch is one of a group of species that are easily damaged by ground fires. Because of its thin bark, even light scorching at the base of a birch tree will lower its resistance to attacks by insects and diseases. And birch is not a prolific sprouter (Lamson 1990). These characteristics are consistent with theories that suggest that periodic ground fires created conditions that favored the development of oak in the understory while discouraging the development of birch and similar species (Crow 1988; Rouse 1986; Reich and others 1990).

Undisturbed stands were once thought to provide optimal conditions for the establishment of oak seedlings (Korstian 1927). In the southern Appalachians, establishment of new seedlings is seldom a management problem. Inventories usually encounter 1,000 or more small red oak seedlings per acre in undisturbed, mature stands, and abundant acorn crops, which usually occur about twice per decade, result in many more oak seedlings becoming established (Loftis 1988). Many of the mature oak stands of today appear undisturbed in the sense that they are fully stocked and no cutting has occurred for several decades. Fire has been controlled and records indicate an absence of fire in many of these stands for 50 to 60 years. Yet, deer population densities have risen to record levels and the impact of deer browsing can be profound (Marquis 1981, Michael 1988).

Results from underplanting seedlings after 5-years suggest little potential for this technique; most discouraging was the lack of height growth. Survival of natural red oak seedlings after overstory removal is a function of the abundance and the size of the advanced regeneration (Loftis 1990a; Sander and others 1976). Since densities of planted seedlings as high as several thousand per acre would be impractical, success with underplanting seem to hinge on the potential size of the individuals before overstory removal. Survival of underplanted red oak seedlings was significantly related to overstory treatment, but height growth was not. In the Ozarks, Johnson and others (1986) found that the survival and growth of underplanted red oak are correlated with initial size of the seedling. Our results may reflect inadequate size characteristics for underplanting red oak in the central Appalachian region.

In the buffer strips of the 60- and 75-percent stocking plots, 20 natural red oak seedlings were sheltered with 5-foot-tall tan Tubex® tree shelters in April 1990. Preliminary results showed that the use of these shelters in shelterwood environments is not encouraging as a method for stimulating the height growth of seedlings. Mortality rates were high and height growth negligible for both areas. Tree shelters reduce solar radiation within the shelter and may not be useful in shelterwood situations. Planting with tree shelters may have more potential when combined with other forms of management that expose the sheltered seedling to full sunlight (Smith 1993b).

The results presented here illustrate the difficulty that forest managers face when attempting to regenerate oak on mesic sites. Managers need to be aware that oak regeneration on mesic sites in the central Appalachians is not achieved through manipulation of stocking levels alone. A better understanding of the role of fire and other forms of disturbances that resulted in long-term dominance by oak seral communities is needed (Abrams 1992; Abrams and Nowacki 1992) before management guidelines can be recommended for natural oak establishment and development prior to overstory removal. Underplanting, as applied in this study, seems to have little potential when combined with reductions in stocking level. Growth of planted seedlings was not sufficient to improve survival probabilities given the limited number of seedlings that can be planted. Until reliable silvicultural guidelines can be developed for the regeneration of oak on mesic sites, prudence should be used when harvesting these stands. If desired ecological conditions include the presence of oak on these productive sites following harvesting activities, partial retention of the preharvest oak component may be the only reliable method to achieve this objective. An oak presence provides a continuous source of hard mast for wildlife, contributes to species diversity, and provides a suitable seed source for future regeneration. If an adequate oak component develops in the regenerated stand, the retained oak trees could be harvested as in the final cut of a shelterwood regeneration, incorporated into two-age management scenarios, or deferred for an additional rotation. If an oak component is not regenerated, future natural regeneration of oak still is possible and the benefits of oak on mesic sites can be retained in part from existing residual trees.

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INTENSITY OF PRECOMMERCIAL CROP-TREE RELEASE INCREASES DIAMETER AND CROWN GROWTH IN UPLAND HARDWOODS

Jeffrey S. Ward[1]

Abstract: In 1988 seven study areas were established in Connecticut to examine the effects of precommercial crop tree release on bole and crown growth. Each study area has 27 8x8 m plots centered on a northern red oak, black oak, or scarlet oak identified as a potential crop-tree (PCT). The 27 plots at each study area were divided into 3 treatments: no cutting, removal of all stems with crowns within 1 m of the crown of a PCT, and removal of all stems with crowns within 1 m of the crowns of a PCT and 2 other potential crop-trees. After cutting, 7191 stems remained. A consequence of crop-tree release is the partial release of trees surrounding crop-trees. The percentage of release of these surrounding trees was assessed in 25% increments. Diameter growth increased with amount of release and crown class. Relative to unreleased trees, 4-yr diameter growth of northern red oak increased by 86%, black/scarlet oak by 65%, red maple by 56%, and black birch by 52%. Release slowed height growth of dominant and codominant oaks for only the first 2 yr. In sapling stands with few oaks in upper canopy positions, precommercial release could be used to augment oak density. Survival and diameter growth of oaks in the intermediate and suppressed crown classes increased with release intensity. Release also increased height growth of northern red oak in the suppressed crown classes.

INTRODUCTION

Approximately 59% of Connecticut's land area is classified as commercial forest and more than half of the forest is oak-hickory (Dickson and McAfee 1988). Many of these forest stands were established around 1900 and are becoming economically mature. Sawtimber stand area has increased from 17% of commercial forest area in 1952 to 35% in 1972. There has been a concurrent 81% increase in the volume of sawtimber harvested (Dickson and Bowers 1976).

One consequence of the increased harvesting is an increase in the number and area of sapling stands. Unfortunately, many sapling stands are dominated by less valuable species such as red maple and black birch. The shift towards more mesophytic species following final harvest of mature oak forests has been noted throughout the central hardwood region (Lorimer 1989). The change in species composition will affect not only the quality and makeup of forest products available to future generations, but will also affect the quality and variety of wildlife habitats (Scanlon 1992).

Precommercial crop-tree release provides an opportunity to simultaneously manipulate stand composition and concentrate growth on individual stems of high value species. Growth concentrated on high value species by crop-tree release increases the value of the mature stand. Increasing the growth of individual stems shortens the rotation by reducing the time needed to grow stems to a desired size. However, crop-tree release is risky in that the management effort is concentrated on relatively few stems (Trimble 1974) and degradation of bole quality is possible (Holsoe 1947, Lamson and Smith 1978, Sonderman 1985, 1986).

Precommercial thinning generally increases individual stem diameters relative to stems in unthinned stands (Downs 1946, Holsoe 1947, Allen and Marquis 1970, Della-Bianca 1975). Although release usually increases diameter growth of northern red oak (Trimble 1974, Lamson and Smith 1978, Lamson 1983, Pham 1985, Sonderman 1985), some

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studies have reported no diameter growth gain (Trimble 1974, Smith 1977, Lamson 1988). Precommercial release has also increased diameter growth of scarlet oak (Mitchell and others 1985), red maple (Marquis 1969, Trimble 1974, Smith 1977, Lamson 1983, Pham 1985, Lamson 1988) and black birch (Smith and Lamson 1983).

The effect of release on height growth is less clearly understood. Downs (1946) and Sonderman (1986) reported increased total height growth was associated with precommercial thinning. Other studies found height growth was unaffected (Hilt and Dale 1982), or reduced (Holsoe 1947, Allen and Marquis 1970) by thinning. Release generally has been reported to have little effect on height growth of oaks (Trimble 1974, Smith 1977, Sonderman 1985, Mitchell and others 1985), red maple (Trimble 1974, Smith 1977, Lamson 1983, Sonderman 1985), and black birch (Smith and Lamson 1983).

Oak may have a 2-stage height growth response to release. Lamson (1983) reported 5-yr height growth of northern red oak was reduced by release, but that heights of released and unreleased trees were similar after 10 yr (Lamson 1988). Similarly, Trimble (1974) found the 5-yr height growth of released and unreleased northern red oak were similar because released trees grew slower for 2-yr and then faster the next 3-yr.

The objective of this study was to determine how intensity of crown release affected survival, diameter and height growth of hardwood saplings. These results will provide information for forest managers considering precommercial crop-tree release to alter stand composition and concentrate growth on selected trees on the eastern boundary of the central hardwood forest.

METHODS

Study Design

Seven study areas (stand ages 7-22 yr) were established in 1988 in western and central Connecticut (Table 1). Canopy closure was complete on all plots at the beginning of the study. Each study area has 27 8x8 meter plots (1/63 ac). Each plot was centered on a northern red, black, or scarlet oak identified as a potential crop-tree (PCT). Within each plot, location of each stem (> 2 cm dbh) was mapped and stem diameter (at 1.4 m aboveground), crown class (Smith 1962), and top height of live crown were recorded. Diameter height was permanently marked with paint. Diameter measurements were to nearest millimeter. Height measurements to the nearest decimeter were made with 10.5 and 13.5 m telescoping poles. A total of 9429 stems were mapped and measured. Diameter and crown class have been

Table 1. Description of study areas used in precommercial thinning study in Connecticut and median initial size of dominant and codominant northern red/black/scarlet oaks.

Study area	Stand age	Site quality	Number of stems on plots		Median initial size	
			Before cutting	After cutting	Dbh (cm)	Height (m)
Tunxis	7	High	2023	1660	4.4	6.3
Hunter's Mountain	11	Medium	1318	972	4.8	6.9
Overlook	12	Low	1414	1120	4.1	5.9
Blueberry	12	Low	1196	920	3.9	5.4
Woodchopper	15	Medium	1185	856	6.0	7.5
Mott Hill	19	High	1128	795	6.8	8.6
Rockytop	22	Low	1165	868	6.7	7.1

measured yearly on all live trees during the dormant season. Because of time constraints, heights were not remeasured on all plots the same year. Heights on the Tunxis plot remeasured in 1989 and 1991. Heights on all other plots were remeasured in 1990 and 1992.

At each study area, the 27 plots were divided among 3 treatments: no cutting within the plot (control); removal of all stems with crowns within 1 m of the crown of a PCT; and removal of all stems with crowns within 1 m of the crown of three PCTs. All cutting was done after the 1988 growing season. After cutting, 7191 stems remained. It became apparent after cutting that many trees surrounding PCTs on the thinned plots had been partially released (Fig. 1). This provided an opportunity to examine growth response to partial release. Therefore, the percent release of trees surrounding PCTs was assessed in 25% increments. This rating system is similar to the free-to-grow rating system detailed in Lamson and others (1990). Trees on control plots were assigned a release factor of 0%.

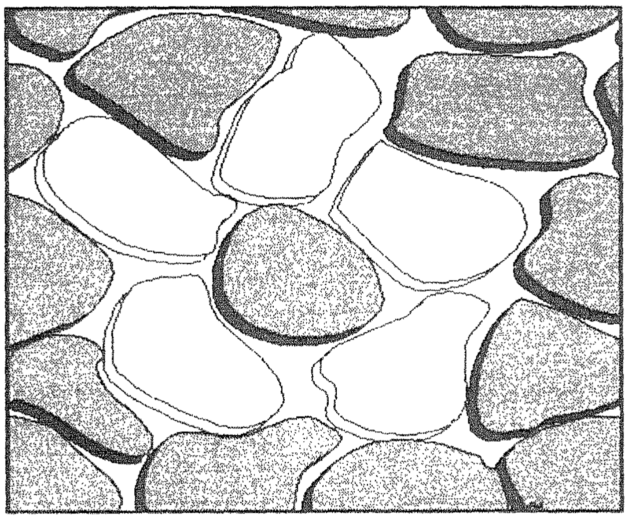

Figure 1. Hypothetical crown map of upper canopy trees with released crop-tree (dark shaded in center), cut trees (unshaded), and surrounding trees.

Data Analysis

Four species groups were selected for analysis: northern red oak (*Quercus rubra*), black/scarlet oak (*Q. velutina*, *Q. coccinea*), red maple (*Acer rubrum*), and black birch (*Betula lenta*). Number of trees in each combination of crown class and species group are shown in Table 2. Tukey HSD test (SYSTAT 1992) was used to test differences in diameter and height growth among crown classes, release categories, and release categories by crown class. Least square means are presented in tables of combined crown classes and release categories to adjust for larger sample sizes in lower crown classes and lesser release categories. Chi-square statistics were used to determine whether mortality/survival was independent of crown class and release factor. Differences were considered significant at $P \leq 0.05$.

Table 2. Number of saplings in Connecticut by crown class, percent release, and species.

Initial Crown class	Percent release	Northern red oak	Scarlet\ Black oak	Red maple	Black birch
Dominant	0-100%	127	129	185	144
Codominant	0-100%	200	203	516	156
Intermediate	0-100%	238	242	704	164
Suppressed	0-100%	188	150	659	131
Combined classes	0- 24%	440	432	1328	398
Combined classes	25- 49%	128	138	406	109
Combined classes	50- 74%	63	69	232	48
Combined classes	75-100%	122	85	98	40
Dominant	0- 24%	54	69	111	90
Dominant	25- 49%	10	16	24	19
Dominant	50- 74%	9	13	29	19
Dominant	75-100%	54	31	21	16
Codominant	0- 24%	103	115	318	101
Codominant	25- 49%	28	28	93	25
Codominant	50- 74%	21	27	62	11
Codominant	75-100%	48	33	43	19
Intermediate	0- 24%	149	161	462	118
Intermediate	25- 49%	53	55	149	32
Intermediate	50- 74%	19	13	72	12
Intermediate	75-100%	17	13	21	2
Suppressed	0- 24%	134	87	437	89
Suppressed	25- 49%	37	39	140	33
Suppressed	50- 74%	14	16	69	6
Suppressed	75-100%	3	8	13	3

RESULTS

Diameter growth

Median diameter of dominant and codominant northern red, black, and scarlet oaks at the beginning of the study ranged from 3.9 cm (1.5 in) on the Blueberry plot to 6.8 cm (2.7 in) on the Mott Hill plot (Table 1). Diameter growth was not independent of either the degree of release or crown class (Table 3). Releasing trees more than 75% (complete release) nearly doubled diameter growth compared with unreleased trees. Diameter growth of dominant trees was more than 5 times greater than for suppressed trees. All crown classes responded to release. Within each crown class, 4-yr diameter growth of completely released trees was approximately 1 cm (0.4 in) more than for unreleased trees.

Table 3. 4-yr diameter growth (cm) of saplings in Connecticut by crown class, percent release, and species.

Initial Crown class	Percent release	Northern red oak		Scarlet\ Black oak		Red maple		Black birch	
Dominant	0-100%	3.08	a[a]	3.38	a	1.81	a	2.88	a
Codominant	0-100%	2.16	b	2.14	b	1.34	b	1.88	b
Intermediate	0-100%	1.33	c	1.25	c	.74	c	1.13	c
Suppressed	0-100%	.83	d	.63	d	.41	d	.65	c
Combined classes	0- 24%	1.37	a	1.42	a	.81	a	1.27	a
Combined classes	25- 49%	1.67	b	1.58	a	.96	b	1.61	b
Combined classes	50- 74%	1.80	b	2.05	b	1.25	c	1.74	b
Combined classes	75-100%	2.56	c	2.34	b	1.26	c	1.92	b
Dominant	0- 24%	2.50	a	2.75	a	1.59	a	2.45	a
Dominant	25- 49%	3.12	ab	3.33	ab	1.57	a	2.96	a
Dominant	50- 74%	-[b]		3.75	b	2.14	b	3.11	a
Dominant	75-100%	3.79	b	3.69	b	1.94	ab	3.00	a
Codominant	0- 24%	1.77	a	1.64	a	.96	a	1.63	a
Codominant	25- 49%	1.84	a	1.82	ab	1.26	b	1.81	ab
Codominant	50- 74%	2.12	a	2.22	bc	1.62	c	1.77	ab
Codominant	75-100%	2.90	b	2.87	c	1.50	bc	2.29	b
Intermediate	0- 24%	.85	a	.92	a	.49	a	.71	a
Intermediate	25- 49%	1.16	b	.71	a	.64	b	1.08	b
Intermediate	50- 74%	1.25	b	1.32	ab	.88	b	1.19	b
Intermediate	75-100%	2.07	c	2.06	b	.94	b	-	
Suppressed	0- 24%	.36	a	.38	a	.19	a	.27	a
Suppressed	25- 49%	.56	b	.48	a	.39	b	.61	b
Suppressed	50- 74%	.91	c	.92	b	.38	b	-	
Suppressed	75-100%	-		-		.68	b	-	

[a] Values within a column followed by the same letter were not significantly different at $P \leq 0.05$. Tested using Tukey HSD test.

[b] Less than 10 trees.

Diameter growth of all species groups was increased by release. Release had a greater effect on the diameter growth of oaks than on red maple and black birch (Table 3). Relative to unreleased trees, 4-yr diameter growth of completely released northern red oaks was increased 1.2 cm, black/scarlet oak by 0.9 cm, black birch by 0.7 cm, and red maple by 0.5 cm. Diameter growth within a crown class for each species group also increased with thinning intensity (Table 3).

Diameter growth of released dominant and codominant trees has been greater than unreleased trees through the first 4 years (Fig. 2). Decreased growth during the 1990 and 1991 growing seasons was probably related to extended mid-summer droughts. Annual diameter growth of northern red oak, black oak, and scarlet were similar and greater than for black birch and red maple.

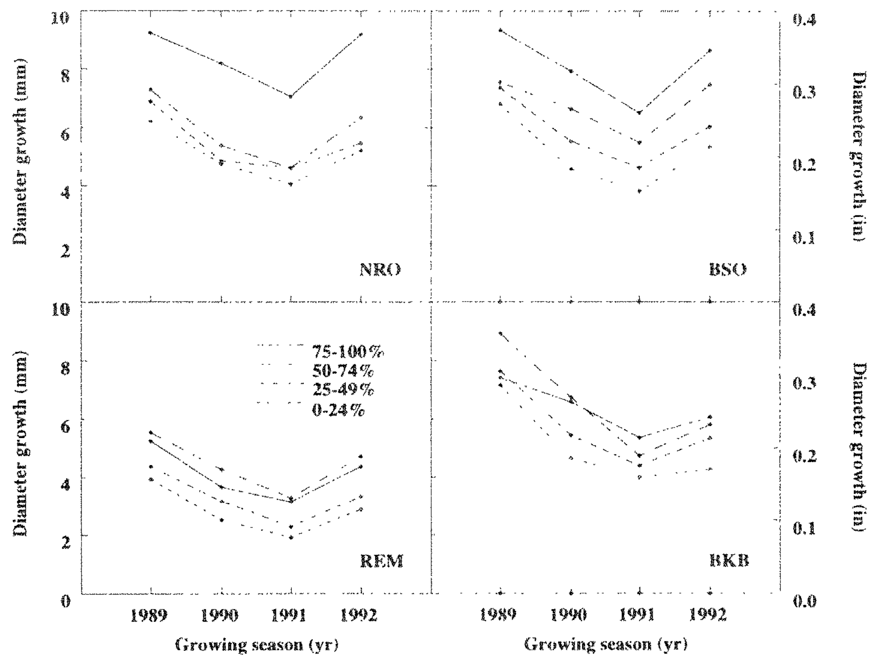

Figure 2. Mean annual diameter growth (mm) of upper canopy trees (dominant and codominant) by year, percent release (0-24%, 25-49%, 50-74%, 75-100%), and species group (NRO-northern red oak, BSO-black/scarlet oak, REM-red maple, BKB-black birch).

Height growth

Median initial heights ranged from 5.4 m (18 ft) on the Blueberry plot to 8.6 m (28 ft) on the Mott Hill plot (Table 1). Median height on most plots was less than the 7.6 m (25 ft) recommended by (Perkey and Wilkins 1994). Height growth was independent of the degree of release, but not crown class (Table 4). Four year height growth of dominant trees, 1.8 m (5.9 ft), was more than 3 times that of suppressed trees, 0.5 m (1.6 ft). There was an interaction between the degree of release and crown class for height growth. Release slowed height growth of taller trees and increased height growth of smaller trees. Height growth of unreleased dominant and codominant trees was greater than for completely released trees. In contrast, height growth of unreleased suppressed trees was significantly less than for trees released 50-75% when, because of small sample size, completely released trees were removed from the analysis.

Release resulted in significant height growth depression codominant black/scarlet oak and red maple (Table 4). Height growth depression of dominant northern red oak by release was not significant ($P \leq 0.058$). Although height growth of suppressed northern red oak and red maple saplings which were completely released was greater than for unreleased trees, the increase was only significant for northern red oak.

Height growth depression on codominant and dominant oaks by release was short-term (Figure 3). ANOVA of height growth between 1988-1990 revealed significant differences among release intensities ($F = 5.56$, d.f. = 3, $P \leq 0.001$). Mean 2-yr height growths between 1988-1992 ranged from 1.0 m for unreleased trees to 0.8 m for completely released trees. There was no significant difference of height growth between 1990-1992 among release intensities ($F = 0.30$, d.f. = 3, $P \leq 0.829$).

Table 4. 4-yr height growth (m) of saplings in Connecticut by crown class, percent release, and species.

Initial Crown class	Percent release	Northern red oak		Scarlet\ Black oak		Red maple		Black birch	
Dominant	0-100%	2.00	a[a]	2.30	a	1.41	a	1.80	a
Codominant	0-100%	1.80	a	1.85	b	1.31	a	1.74	a
Intermediate	0-100%	1.31	b	1.38	c	.88	b	1.44	a
Suppressed	0-100%	.71	c	.52	d	.50	c	.64	b
Combined classes	0- 24%	1.38	a	1.54	a	1.12	a	1.28	a
Combined classes	25- 49%	1.44	a	1.44	a	1.05	a	1.35	ab
Combined classes	50- 74%	1.49	a	1.60	a	.99	a	1.70	b
Combined classes	75-100%	1.51	a	1.47	a	.95	a	1.29	ab
Dominant	0- 24%	2.01	a	2.30	a	1.60	a	1.78	a
Dominant	25- 49%	2.26	a	2.38	a	1.51	a	1.98	a
Dominant	50- 74%	-[b]		2.31	a	1.31	a	2.01	a
Dominant	75-100%	1.70	a	2.21	a	1.22	a	1.42	a
Codominant	0- 24%	1.97	a	2.03	a	1.45	a	1.83	a
Codominant	25- 49%	1.72	a	1.81	ab	1.39	ab	1.62	a
Codominant	50- 74%	1.71	a	1.92	ab	1.30	ab	1.89	a
Codominant	75-100%	1.79	a	1.66	b	1.11	c	1.62	a
Intermediate	0- 24%	1.23	a	1.36	a	1.02	a	1.07	a
Intermediate	25- 49%	1.38	a	1.23	a	.84	a	1.43	a
Intermediate	50- 74%	1.22	a	1.60	a	.84	a	1.65	a
Intermediate	75-100%	1.40	a	1.31	a	.83	a	-	
Suppressed	0- 24%	.29	a	.49	a	.41	a	.44	a
Suppressed	25- 49%	.41	ab	.32	a	.46	a	.38	a
Suppressed	50- 74%	1.00	b	.59	a	.50	a	-	
Suppressed	75-100%	-		-		.63	a	-	

[a] Values within a column followed by the same letter were not significantly different at $P \leq 0.05$. Tested using Tukey HSD test.
[b] Less than 10 trees.

Mortality

Release reduced 4-yr mortality rates for smaller, but not larger trees (Table 5). Mortality rates were significantly different among release levels for suppressed ($\chi^2 = 47.60$, d.f. = 3, $P \leq 0.001$) and intermediate trees ($\chi^2 = 8.15$, d.f. = 3, $P \leq 0.043$). Mortality rates for unreleased suppressed and intermediate trees was more than 3 times higher than for completely released trees. Releasing suppressed trees decreased mortality for all species groups (Fig. 4). Mortality rates of codominant and dominant trees were independent of release intensity (Table 5).

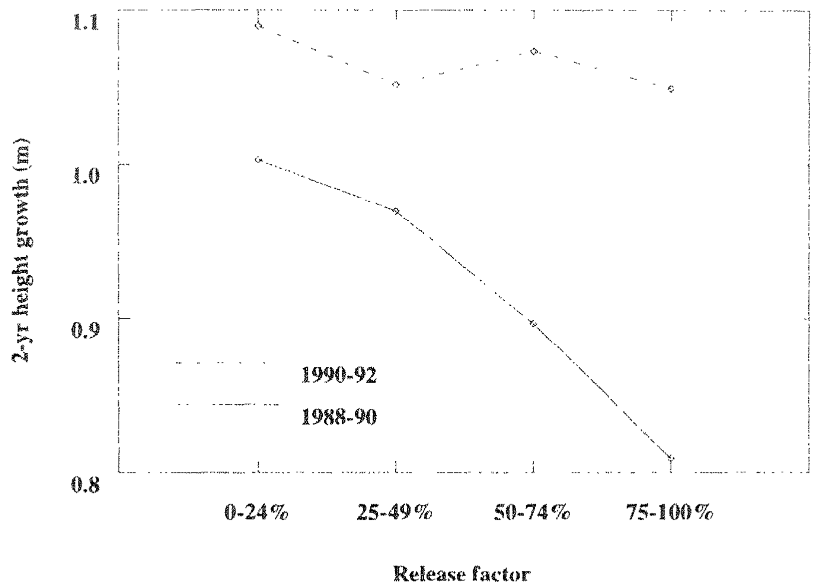

Figure 3. 2-yr height growth (m) of upper canopy oaks between 1988-1990 and 1990-1992 by percent release.

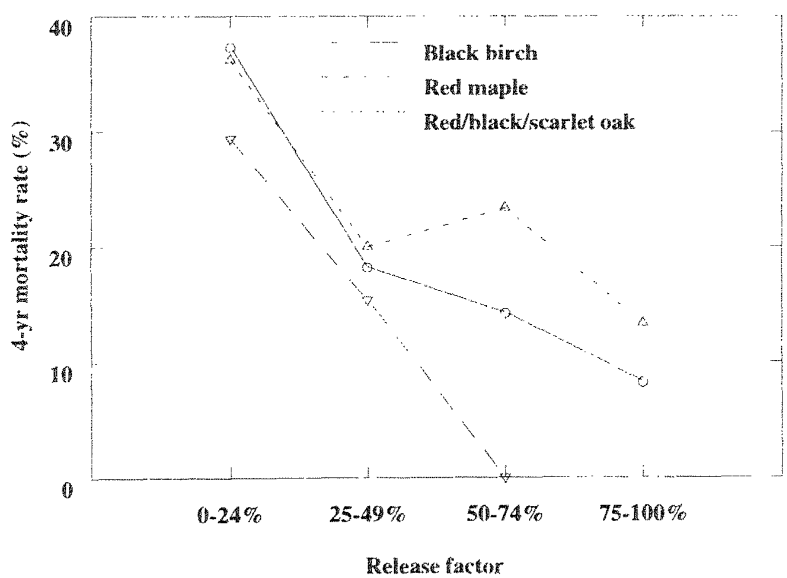

Figure 4. 4-yr mortality rates of suppressed trees by percent release and species group.

Table 5. 4-yr mortality rates (%) of saplings in Connecticut by crown class and release intensity.

	Crown class in 1988			
Percent release	Suppressed	Intermediate	Codominant	Dominant
0- 24%	35.8	6.2	1.9	1.8
25- 49%	18.9	2.4	1.7	1.4
50- 74%	20.0	4.9	0.8	0.0
75- 100%	10.0	1.9	2.1	2.4

DISCUSSION

Precommercial thinning increased diameter growth of both dominant and codominant trees. Both the diameter growth and the increase in growth with degree of release are similar to results in West Virginia (Lamson and others 1990). Not surprisingly, diameter growth response to complete release was greater for codominant trees, 80% increase, than for dominant trees, 47% increase. The diameter growth response of oaks was better than for red maple and black birch (Table 3). Released trees have continued to grow faster than unreleased trees for 4-yr after thinning. An earlier study suggests diameters of released trees should continue to grow faster than unreleased trees for 6 yr (Lamson 1988).

Unfortunately, release also decreased height growth of dominant and codominant oaks (Fig. 3). However, the depression of oak height growth was short-term and height growth 2-4 yr after release was independent of release. Trimble (1974) reported height growth of northern red oak was slower for 2 yr after release and then faster for next 3 yr. Because diameter growth of released upper canopy oak saplings continues to be greater than for unreleased trees, the short-term decreased height growth appears to be a transient and inconsequential phenomenon.

Precommercial crop-tree release dramatically and significantly increased diameter growth of saplings in intermediate and suppressed crown classes (Table 3) without negatively impacting height growth (Table 4). Releasing suppressed oaks was especially effective. Relative to unreleased trees, diameter growth of completely released intermediate trees increased by 145% and suppressed trees by 226% (Table 3). This study found that young suppressed oaks can response positively to release, unlike older suppressed oaks (Sander 1977). Reducing stocking to 10% doubled diameter growth of suppressed and intermediate oaks and yellow-poplar (Allen and Marquis 1970). Diameter growth of intermediate northern red oaks was increased by a cutting all trees within 5-ft of each crop-tree (Trimble 1974). However, partial release often does not increase diameter growth of intermediate oak saplings (Smith 1977, Lamson and Smith 1978). While this study did not find that release increased height of intermediate northern red oak as reported by Lamson and Smith (1978), release did not decrease height growth of intermediate oaks. Height growth of suppressed northern red oak was increased by release (Table 4).

There is little doubt that an immediate benefit of precommercial thinning is reduced mortality rates in the suppressed and intermediate crown classes (Fig. 3). Reduced mortality following precommercial thinning has been noted for northern red oak (Trimble 1974, Della-Bianca 1983, Pham 1985), scarlet oak (Mitchell and others 1985), and red maple (Trimble 1974, Pham 1985).

These results indicate that not only can precommercial release be used to increase growth of larger trees (Trimble 1974, Smith 1977, Lamson 1983,1988), but also intermediate and suppressed trees (Allen and Marquis 1970). The ability of suppressed oak saplings to respond to release provides forest managers with a technique to increase oak densities in sapling stands with few oak in upper canopy positions. It is likely that suppressed and intermediate trees will need to be released at least once more to assure their continued presence in the upper canopy. While precommercial crop-tree release is difficult to justify on an economic basis (Dwyer and others 1993), the practice may be profitable for valuable species on high quality sites (Miller 1986). Increasing oak density also increases wildlife and esthetic values.

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INDIVIDUAL TREE- VERSUS STAND-LEVEL APPROACHES TO THINNING: IS IT A CHOICE OF ONE OR THE OTHER, OR A COMBINATION OF BOTH?

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Abstract: Thinning guidelines have existed for most eastern hardwood forests for 20 to 30 years. While these guidelines are presented in varying degrees of detail, they generally all contain recommendations on levels of residual stand density and stand structure, along with information on crop tree requirements. Recent attempts have been made to simplify thinning guidelines by using an individual tree approach, referred to as "crop tree management". This is in contrast to the "area-wide approach", which purportedly focuses on the stand-level alone. In this paper, I will show how the two approaches can be used together to improve thinning practice. In such a combined approach, the main focus of thinning remains on the crop tree, and the long standing tools of stand density and stand structure are used to direct stand development along desired paths.

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