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MECHANICAL DAMAGE INCURRED BY UNDERPLANTED NORTHERN RED OAK FOLLOWING SIX OVERSTORY TREATMENTS: FIRST-YEAR RESULTS

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Abstract—Regenerating oak, on recently harvested sites, continues to be a silvicultural challenge in the Central Hardwood Region. Enrichment planting can increase oak regeneration potential and success during the early stages of cohort development. In April of 2002, a replicated oak silviculture study using artificial regeneration was established near Oak Ridge, TN. Nursery-grown, 1-0, bareroot northern red oak (*Quercus rubra* L.) seedlings were underplanted prior to timber harvesting. Six overstory treatments, no cut (control), silvicultural clearcut, commercial clearcut, and 50, 25, and 12.5 percent basal area (BA) retentions, were implemented after planting, with each being replicated 3 times for a total of 18 overstory treatment units. Seedlings were assigned to harvest damage classes in order to assess the effect of operational damage on their growth and competitiveness. There were no significant differences in mortality between the cutting treatments, but mortality as high as 83 percent (12.5 percent BA retention) suggested substantial losses due to harvesting. Twig damage differed significantly between cutting treatments ($P < 0.05$). Pre-harvest underplanting in mature stands similar to those treated in this study resulted in high seedling mortality and varying levels of damage, depending on harvest intensity.

INTRODUCTION

Regenerating oak-dominated (*Quercus* spp.) stands continues to be a difficult endeavor throughout the Eastern deciduous forest. This problem is directly related to the paucity of oak regeneration in the subcanopy of oak-dominated stands. Oak regeneration success is strongly linked to the presence of oak in the advance regeneration pool (Larsen and Johnson 1998). The absence of numerous, large oak advance regeneration in oak-dominated stands prior to canopy disturbance can lead to the replacement of oaks by faster growing species and, also, more shade-tolerant species (Johnson 1993, Loftis 1990, Sander 1972). The issue of oak replacement is more acute on productive sites, since competition is more aggressive (Loftis 1983, Rogers and Johnson 1998). Furthermore, the inadequacy of oak seedling establishment after disturbance exacerbates the oak regeneration problem, since there is little contribution to early stand development from oak seedlings that germinate after disturbance (Loftis 1990, McGee and Hooper 1970).

Large oak advance regeneration is necessary because small seedlings do not respond quickly to growing space release, which allows faster growing competitors to overtop and suppress small oak regeneration (Loftis 1990, Sander 1972). The development of large oak advance regeneration can take a decade or longer (Sander and others 1983). Many landowners are not willing to invest in the time and expense required to develop adequate oak advance regeneration before final harvest.

An alternative to natural oak regeneration is artificial regeneration. Nursery-grown seedlings can supplement natural oak regeneration and cut down on the time required to develop adequate advance regeneration (Wendel 1980). The decision to plant either before or after harvesting must involve the advantages and disadvantages of both techniques. Planting after harvest can subject seedlings to intense temperature and moisture fluctuations, which can stress seedlings as they adjust to field conditions, but precludes harvesting damage. Underplanting prior to harvest will allow seedlings to adjust to field conditions ameliorated by a canopy, yet harvest damage to seedlings is inevitable (Dey and Parker 1997). Operationally, planting after harvest can be more difficult than planting before harvest because of planting in and around logging residues. Knowing the impacts of harvest intensity on underplanted seedlings can help foresters calculate expected losses in order to implement a successful planting operation. The objective of this study is to evaluate the effects of timber harvesting on physical damage to underplanted seedlings.

STUDY SITE

In fall 2001, a 75-acre harvest and oak regeneration study was initiated at the University of Tennessee's Forestry Experiment Station in Oak Ridge, TN. The Oak Ridge Experiment Station is located within the Ridge & Valley Physiographic Province within the Central Hardwood Region. The study site was a mixed hardwood assemblage composed primarily of upland oaks, yellow poplar (*Liriodendron tulipifera* L.), and various shade-tolerant hardwoods, such as red and sugar maple (*Acer rubrum* L. and *A. saccharum* Marsh., respectively).

METHODS

High quality northern red oak (*Quercus rubra* L.) seedlings were outplanted to evaluate the efficacy of preharvest enrichment planting and overstory removal in regenerating oak. Seedlings were provided by the University of Tennessee's Tree Improvement Program. The seedling stock was graded using an ocular system based on size and condition. Seedlings were separated into three grades: premium, good, and potential cull. Only premium and good seedlings were outplanted.

The experimental design is a randomized block design (RBD). Block differences were determined to be significant

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using pre-harvest stand basal area data. A total of three replicate blocks were used and each block was divided into six overstory treatment units.

Six overstory treatments were implemented during the late spring and early summer of 2002. The overstory treatments are: (1) silvicultural clearcut (SCC), (2) commercial clearcut (CCC), (3) 12.5 percent basal area (BA) retention, (4) 25 percent BA retention, (5) 50 percent BA retention, and (6) no cut (control). The basal area retention units were marked in order to create a uniformly distributed residual stand. The treatments were assigned at random within 3 complete blocks for a total of 18 experimental units of approximately 4 acres each.

Within each treatment block, 60 1-0 bareroot seedlings were planted prior to the harvesting sequence. Both shovels and an auger were used in the planting operation. Seedlings were planted on a 20- by 20-foot spacing to facilitate their relocation for measurement. The seedlings were concentrated toward the center of each block to avoid edge effects.

Outplanted seedlings were examined following the harvest operation to determine the type and magnitude of damages they sustained. A seedling damage classification system was developed to provide a framework for characterizing seedling condition, identifying the forms of damage, and quantifying mechanical damage associated with the harvest treatments. Seedling survival was determined for the 2002 growing season only. Therefore, any seedling not showing vital signs (i.e. bud break, sprouting) was assumed dead. Damage to live seedlings was separated into stem and twig categories for analysis. In the control units, seedling stem dieback was viewed as stem damage, while twig dieback and herbivory were recorded as twig damage.

All statistical analysis was conducted using SAS software (SAS Institute Inc. 2001). Mixed model analysis of variance (MMAOV) was used to determine the effects of the overstory removal treatments in relation to seedling survival and damage. For survival, this was determined by testing whether mortality varied between treatment units. Mortality in this case was the summation of top-killed, killed (uprooted or without vital signs), and missing (seedling not found, therefore, status unconfirmed) seedlings minus the number of sprouting top-killed seedlings. The mortality figure was converted into a percent mortality for each treatment unit. Analysis of damages incurred by living seedlings was conducted to test for treatment effects. Stem and twig damage values represent the number of seedlings in each treatment unit displaying those damages. Associations between mortality, stem damage, and twig damage were evaluated through correlation analysis.

Tukey's HSD was performed in order to identify which means differed when MMAOV found significant treatment effects. Contrasts were used to determine if specific combinations of treatments differed significantly. The patterns of response (linear, quadratic, etc.) for percent mortality, twig damage, and stem damage across the treatment levels were explored using orthogonal polynomial contrasts.

RESULTS

Seedling Survival

Treatment effects on seedling mortality were significant at the 5 percent level (table 1). Tukey's mean separation indicated that the significant differences exist between the 12.5 percent BA retention (83 percent mortality) and the control (42 percent mortality). However, this result occured only when the control units were included in the analysis. Mean separation confirmed this result by grouping all overstory removal treatments together. Therefore, there were no significant differences in seedling survival between the cuttings.

Contrast analysis of the combined effects of complete removal treatments (silvicultural and commercial clearcuts) against partial cutting treatments (12.5, 25, and 50 percent BA retentions) on seedling mortality was not significant at the 5 percent level. This result is similar to the findings of Tukey's mean separation. Orthogonal polynomial contrasts identified that seedling mortality changed linearly across the harvest intensity gradient ($P < 0.05$), while all other patterns (i.e., quadratic and cubic) were not significant.

Seedling Damage

MMAOV indicated that the harvest treatments had significant effects on twig damage to live seedlings at the 5 percent level but not stem damage (table 1). Tukey's mean separation for twig damage means indicated that there were significant differences between the cutting treatments. Specifically, the 50 percent BA retention mean (27 seedlings damaged) was not grouped together with the commercial clearcut or the 12.5 percent BA retention means (both with 9 seedlings damaged) (table 1).

Table 1—Treatment and control means for a harvest and oak regeneration study at the Oak Ridge Forestry Experiment Station, TN

	Overstory treatment levels					
Seedling status	Control	50	25	12.5	CCC	SCC
Percent mortality	42b	57ab	75ab	83a	78ab	76ab
Twig damage	10ab	27a	16ab	9b	9b	10ab
Stem damage	8a	24a	12a	8a	12a	13a

CCC = commercial clearcut; SCC = silvicultural clearcut.
Means are percent mortality, number of seedlings with twig damage, and number of seedlings with stem damage of underplanted northern red oak (*Quercus rubra* L.) for 2002. Means followed by the same letter are not statistically different according to Tukey's HSD at $\alpha = 0.05$.

Since treatment effects on stem damage were not found to be statistically significant, contrast analysis was only performed for twig damage means. Two combinations of treatment means for twig damage were explored for significant differences. The same contrast used in the seedling mortality analysis (clearcuts vs. retentions) was used for twig damage. Contrast analysis found the two combinations to be significantly different ($P < 0.05$). The average of the SCC, CCC, and 12.5 BA percent retention means were compared to the average of the 25 and 50 BA percent retention means due to Tukey's mean grouping (table 1). Contrast analysis found the two groupings to be significantly different ($P < 0.05$). The orthogonal polynomial contrast for twig damage showed a significant quadratic and cubic pattern of change across the harvest intensity gradient ($\alpha = 0.05$). The quadratic pattern of twig damage emerged across the cutting treatments and decreased as harvest intensity increases. The cubic pattern arises at the low end of the removal intensity gradient where there was a sharp increase in twig damage moving from the controls to the 50 percent BA retention units.

Seedling Mortality and Damage

Correlation analysis for both mortality and damage factors were conducted with a 3 by 3 matrix of percent mortality, stem damage, and twig damage (table 2). The analysis indicated significant associations between both percent mortality and twig damage with stem damage ($P < 0.05$). The correlations between both percent mortality, and twig damage with stem damage were –0.48 and 0.79, respectively.

DISCUSSION

Seedling survival for the 2002 growing season was linked to harvesting. Although mean separation was unable to find significant differences between the cutting units, the analysis did find that mortality in cutting units was significantly greater than in control units (table 1). Although control units were undisturbed by logging, dieback mortality of planted seedlings did occur in the control units. The seedling's intolerance to overhead shade and water stress associated with the 2002 summer dry spell probably contributed to this mortality.

Although there were no significant differences between the cutting units, seedling mortality was observed to be greatest in the 12.5 percent BA retention, CCC, and SCC units.

Table 2—Correlations of three response variables measured in a harvest and oak regeneration study at the Oak Ridge Forestry Experiment Station, TN in 2002

	Percent mortality	Twig damage	Stem damage
Percent mortality	1	-0.43 P > 0.05	-0.48* P < 0.05
Twig damage		1	0.8* P < 0.0001
Stem damage			1

Matrix with percent mortality, twig damage, and stem damage showing correlation coefficients and *P*-values. Correlation coefficients followed by an asterisk are statistically significant at $\alpha = 0.05$.

High mortality in these units is likely the result of a combination of factors. One obvious explanation is the high cutting intensity, which led to increased felling and skidding. With increased felling comes heavy damage to midstory and understory vegetation. The more widely spaced trees in the residual stand were less restrictive to skidding. This allowed operators to skid timber freely with little worry of damaging residual trees. The lower mortality in the 25 percent and 50 percent BA retention units indicated that skidding might be more concentrated on areas where damage to residual trees was less likely. Furthermore, the openness of the intensely harvested units may have stressed seedlings and caused mortality through increased exposure to solar radiation and desiccating winds.

A linear pattern of mortality across the overstory removal treatments was found, indicating that seedling mortality increased linearly along the overstory removal gradient.

Twig damage was the only type of damage that was significantly impacted by overstory removal (table 1). The 50 percent BA retention treatment had the highest level of twig damage while the commercial clearcut and 12.5 percent BA retention units had the least. This is practically the inverse of the mortality trend. There was less severe destruction of understory vegetation in the 50 percent units, since fewer trees were harvested and the higher retention restricted skidders from meandering across these units. Instead, skidding was concentrated in areas where damage to residual trees could be avoided. The partial cutting in the 50 percent retention units created more low-level damage, such as twig breakage, compared to the intense removal treatments (clearcuts and 12.5 percent retention). The primary reason for less twig damage in the SCC, CCC, and 12.5 percent retention units was due to higher mortality, which left few intact seedlings that could sustain twig damage. Although it is likely that a substantial number of seedlings categorized as dead in the SCC, CCC, and 12.5 percent units sustained twig damage, mortality precluded the identification of twig damage to seedlings in this study.

Twig damage in the partial cutting units versus complete cutting units indicated that the two treatment combinations were significantly different from each other. This result showed that one can expect partial cutting to have a different impact on seedling damage compared to complete cutting. The groupings of the twig damage means showed a more complex pattern in relation to partial cutting and complete cutting. The MMAOV and mean separation of twig damage indicated the 50 and 12.5 percent BA retention units were significantly different, which is inconsistent with the results of the partial vs. complete cut contrast. Instead, a contrast of the complete cuts + 12.5 percent retention and the 25 and 50 percent retentions was performed and indicated a strong significant difference ($P < 0.002$). This result implied that one can expect that a combination of intense partial and complete cutting will cause significantly different levels of damage to underplanted seedlings compared to moderate partial cutting.

The response in twig damage across the overstory removal gradient followed both quadratic and cubic patterns in this study. The quadratic pattern occurred across the cutting treatments (table 1). Specifically, twig damage decreased exponentially as harvest intensity increased producing a concave pattern. This translated into a rapid decrease in twig damage moving from the 50 percent retention to the 12.5 percent retention and a leveling out across the clear-cut units. The cubic pattern appeared because of the influence of the control units. At the low end of the removal gradient, there was a dramatic increase in twig damage moving between the controls and 50 percent units followed by a noticeable decrease continuing on to the 25 percent units. This peak represented a cubic change in twig damage across this section of the overstory treatment gradient.

The two significant correlations between seedling mortality and stem damage, r = -0.48, and twig damage and stem damage, r = 0.79, recapitulated the relationship between harvesting and damage to underplanted seedlings observed in this study (table 2). A moderate negative association between seedling mortality and stem damage translated to an increase in mortality being accompanied by a decrease in stem damage. Although not statistically significant, higher mortality was experienced in units with greater harvesting intensity, which produced greater destruction of underplanted seedlings. Therefore, seedlings were more prone to total stem destruction following intense overstory removal compared to low-level damage, such as stem damage. A strong positive correlation between twig damage and stem damage suggested the two covary. Seedling damage was greatest for the moderately intense cutting treatments where low-level damage predominated. Specifically, an increase in twig damage was accompanied by an increase in stem damage and the two changes were directly linked. In other words, seedlings that experienced twig damage also incurred stem damage.

CONCLUSIONS

First year results indicate that underplanting in conjunction with harvesting can substantially impact seedling survival. With as much as 83 percent mortality (12.5 percent retention) and no statistical differences in seedling mortality between the cutting treatments, a significant loss of underplanted seedlings can be expected when harvesting in stands similar to those treated in this study. However, since these are one year results, the seedling mortality figures may be overestimates due to potential sprouting of seedlings formerly classified as dead (end of the 2002 growing season) during the 2003 growing season.

The assessment of twig damage showed that moderate basal area removal generated substantial damage with the 50 percent BA retention resulting in twig damage to nearly half (mean = 27) of the seedlings in those units. Furthermore, it is likely that twig damage was severe in the heavily cut units but was masked by high mortality. The study area consisted primarily of mature forest, which may have exaggerated the amount of damage incurred by the seedling stock. An alternative to underplanting in mature stands would be to plant after harvest and avoid any negative direct impacts related to harvesting large timber. Post-harvest planting is, however, more logistically difficult, because of logging residue.

Harvesting effects on seedling survival and damage may have been exacerbated by the short time interval between the planting operation and timber harvesting. The seedlings were subjected to multiple episodes of handling before out-planting and were likely in a state of shock from being lifted from a favorable nursery setting and placed in the field. The sudden alteration of the microenvironment brought about by harvesting may have overwhelmed many of the seedlings, since they were acclimating to field conditions when harvesting took place and also had little time to put down roots to resist uprooting and facilitate sprouting. This point suggests that underplanted seedlings may require a few growing seasons of adjustment before overstory removal.

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Station ID: GTR-SRS-071

Description: Ninety-two papers and thirty-six poster summaries address a range of issues affecting southern forests. Papers are grouped in 15 sessions that include wildlife ecology; fire ecology; natural pine management; forest health; growth and yield; upland hardwoods - natural regeneration; hardwood intermediate treatments; longleaf pine; pine plantation silviculture; site amelioration and productivity; pine nutrition; pine planting, stocking, spacing; ecophysiology; bottomland hardwoods - natural regeneration; and bottomland hardwoods—artificial regeneration.