ABSTRACT

SAN FILIPO, TRACY HALLEY. A Crop Tree Release of White Oaks, Yellow Poplars, and Northern Red Oaks in Young Naturally Regenerated Mixed Species Stands. (Under the direction of Daniel J. Robison.)

This study involves northern red oaks, white oaks, and yellow poplars selected as crop trees in even aged mixed species stands, with initial treatments applied when the three stands used had been clear cut 6, 8, and 14 years earlier. The treatment categories included a control (C), a mechanical release (M), a contemporaneous mechanical and chemical release (MC), an initial mechanical release with a chemical release in the following growing season (MC2), and a mechanical and chemical release combined with fertilization (MCF). Survival was high across all treatments, ages, and species. Although treatments were significant at p=0.0711 when the 2001, 2004, and 2010 volumes were used together as a response variable, the 1998 volume, the age of the stands, and the species each accounted for more of the variation. When the treatments were compared within species and age combinations, only a few of them were significantly greater than the control. No clear choice of a treatment emerged. Releasing a larger area around each crop tree may lead to better results.

A Crop Tree Release of White Oaks, Yellow Poplars, and Northern Red Oaks in Young Naturally Regenerated Mixed Species Stands

by
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Biography

Tracy San Filipo was born in Karratha, Western Australia. She grew up in New Jersey and North Carolina. After obtaining an undergraduate degree in Environmental Studies from Mount Holyoke College, she came to NC State to study forestry.

Acknowledgements

Larry Jervis, Heather Williams, Dan Robison, and Corbitt Simmons designed and implemented this study. Fikret Isik and John Frampton assisted with the choosing of appropriate statistical methods for the analyses in this paper. Dan Robison and Ted Shear were a tremendous help in writing this.

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Introduction and Literature Review

It was projected that the growth of hardwoods in the Southeastern USA would only exceed the rate of removal until 2025, after which stocks of hardwoods would decrease as they would be cut faster than they would be replaced (Prestemon and Abt 2002). Unlike pine plantations, strategies for increasing hardwood production are not fully developed (Prestemon and Abt 2002). Projections of a high future demand for hardwoods led to concerns about the potential supply in the Southeast, which spurred this research.

Over 80% of the potential supply of hardwoods in the South is in the possession of non-industrial private forest (NIPF) landowners. Following a clearcut, natural regeneration rather than plantings is usually relied upon to restock hardwoods. Although oaks and other desirable hardwoods naturally regenerate in the Piedmont region, these hardwoods typically grow within a matrix of less valuable species, resulting in less than optimal prospects for future harvests. Silviculture techniques such as precommercial thinning or crop tree release can be good options for landowners seeking to increase the density of desirable species through improved survival and reduce the rotations lengths through improved growth. Historically, choosing crop trees among young hardwoods (less than 15-20 years of age) was considered inefficient because differences in the potential of the hardwoods being selected were not yet apparent. Recent studies of young hardwoods in New England indicate that releases at young ages may be successful. A study in Connecticut begun in 1988 indicated that when saplings of crop species aged 7-22 years were released, the diameter growth of northern red oaks (*Quercus rubra*) over four years was 86% greater (Ward 1995). For dominant and codominant saplings, height growth was temporarily reduced; for suppressed saplings, height growth increased. Saplings with suppressed or intermediate initial canopy positions had improved survival with release. After eighteen years, complete release resulted in improved survival for trees that started in intermediate or codominant positions and in larger diameters for trees that started in dominant or codominant positions (Ward 2009).

Releases of 12-year-old yellow poplars (*Liriodendron tulipifera*) in West Virginia led to diameter increases of 33%-72% (Lamson and Smith 1989). In contrast, the heights of these trees increased less than those of the control. When all residual woody vegetation taller than 5ft was cut following a harvest of commercially valuable trees in Indiana, yellow poplar seedlings grew to be substantially taller and to have larger diameters, than when only the residual trees with dbhs over 6 inches were cut or when over 40 square feet per acre of residual vegetation was left in place (Beck and Della-Bianca 1981). The release of 10-year-old yellow poplars in Virginia increased diameter growth, temporarily decreased height growth, and resulted in higher biomass (Johnson, Bollig, and Rathfon 1997 and 1998).

A recent study of 7-year-old hardwoods in North Carolina found that thinning the trees from 8,500 per acre to 3,000 per acre did not increase growth of individual trees, but that fertilizing with nitrogen and phosphorus did (Newton et al. 2002). In another study, several species of hardwoods in a 2-year-old stand experienced greater height growth with nitrogen and phosphorus fertilization (Berenguer et al. 2009). Yellow poplar was among these species, and also increased in groundline diameter and volume. The red oak species increased in height, but the white oak species did not. Berenguer (2006) observed overall increased growth on a 2-year-old naturally regenerated stand with fertilization treatments involving a combination of nitrogen and phosphorus or a combination of nitrogen, phosphorus, and potassium, but not with a nitrogen treatment.

Although release has the potential to increase the height and diameter of trees, it may also adversely affect log quality. Epicormic branching and lower crowns can be stimulated by excessive thinning (Strong et al. 1995). Large epicormic branches may lower the quality of the potential logs and lower crowns may reduce the height of the tree that is useable. Epicormic branching may be less prevalent among dominant or codominant trees.

Objectives

The objectives of this research were to determine if yellow poplar (*Liriodendron tulipifera*), white oak (*Quercus alba*), and/or northern red oak (*Quercus rubra*) have improved growth or survival when released in 6, 8, or 14-year-old stands in the Southeastern US. Secondary areas of inquiry were interactions between release and fertilization, and whether the release allowed for an increase in epicormic branching, ground cover, or the number of trees within 1.8 meters of the crop tree.

Methods

Site Description

The G. W. Hill Demonstration Forest is a teaching and research forest managed by North Carolina State University and located in Durham County, North Carolina. Durham County is in the northern part of the Southern Piedmont and has an average annual temperature of about 15º C and an average annual rainfall of about 120 cm (http://www.nc-climate.ncsu.edu/cronos/normals.php?station=312515). In 1997, three similar forest stands at Hill Forest were selected for use in this study[1]. Based in part on the species and abundances that were present on these sites, the three hardwood species selected for this study were yellow poplar, white oak (*Quercus alba*), and northern red oak. The three even-aged naturally regenerated forest stands, in rolling Piedmont topography, used in the study were as follows:

1) The youngest stand was clear-cut in the fall of 1992 and therefore the stand was 6-years-old at the start of the study in 1998. The stand, prior to the clear-cut, was 90-years-old and composed primarily of yellow poplar, hickories, oaks, and other mixed hardwoods. Area I is 3.2 ha, has 6-10% slopes on a lower slope position, an easterly aspect, and soils are Georgeville silt loam (Jervis *et al*. 1999). In 1996, Area I was stocked with about 5,189 red and black oak per ha, 988 white oak per ha, and 19,274 yellow poplar per ha.
2) The second youngest stand was clear-cut in September of 1990 and therefore the stand was 8-years-old at the start of the study. The stand, prior to the 1990 clear-cut, was about 60-years-old and composed of mixed hardwoods, including yellow poplar, hickories and oaks, as well as Virginia pine. Area II is 4.25 ha, has 2-10% slopes on

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[1] Stand F-11, F-45 and B-18 are referred to as the 6-year-old stand/18-year-old stand, the 8-year-old stand/20-year-old stand, and the 14-year-old stand/26-year-old stand, respectively, for the purposes of this paper.

an upper slope position, a northerly aspect and soils are Georgeville silt loam and Herndon stony silt loam (Jervis *et al*. 1999). In 1996, Area II had about 3,212 red and black oak per ha, 1,236 white oak per ha, and 6,425 yellow poplar per ha.

3) The oldest stand was clear-cut in January of 1985 and therefore the stand was 14-years-old at the start of the study. The stand, prior to the 1985 clear-cut, was at least 40-years-old and composed primarily of white oak, yellow poplar, northern red oak, black oak, short leaf pine, and American beech. Area III is 4.57 ha, has 6-15% slopes on a midslope position, a northerly aspect, and soils are mostly Georgeville silt loam (Jervis *et al*. 1999). In 1996, Area III had about 887 red and black oak per ha, 596 white oak per ha, and 3,484 yellow poplar per ha.

On all three sites the harvests were silvicultural clear-cuts that included return in the year after harvest to remove any live residual large trees. Subsequent to the clear-cuts, until the initiation of the study treatments, no silviculture treatments were conducted on any of the sites.

Experimental Design

The desired condition was about 75 trees of each of the three species selected on each of the three sites, for a total study of more than 600 trees. Each selected tree needed to meet the following criteria:

- yellow poplar, white oak, northern red oak or black oak (*Quercus velutina*)[2].
- codominant or dominant in the canopy surrounding them, but not emergent.
- not be from obvious stump sprout origin[3].
- at least 6 meters away from any other study tree.
- within 6 meters of the transect line they were associated with for spacing purposes.

[2] Black oak was considered overly difficult to distinguish from northern red oak at the young ages relevant to the study; instead of attempting to exclude black oak from the study, it was acknowledged that some of the trees in the northern red oak category were probably black oak.
[3] Trees were considered obvious stump sprouts if they were from a visible stump larger than 5 centimeters.

During the summer of 1998, line transects were created across each stand along cardinal directions, and study trees were selected along each line about every 12 m. This process yielded the selection of 233 northern red oaks, 191 white oaks, and 235 yellow poplars for a total of 659 trees. These trees were marked with numbered tags, and their locations were recorded. Each stand was divided into three blocks for each species- one on an upper slope, one middle slope, and one lower slope. The boundary lines dividing the stands into blocks varied slightly for each species to better balance the number of trees of each species in each block.

Treatments were a priori randomly assigned within blocks, but some trees were reassigned to a different treatment to create a more balanced array. The treatments included:

(1) mechanical release (M): brush saws and chainsaws used to clear a circle of all woody vegetation in a 1.8 meter radius centered on the study tree; if large trees outside of the 1.8 meter radius had a crown that extended over the circle, they were also cut. If a study tree was over 6 meters tall, the radius of the circle was increased to match 30% of the tree's height,

(2) mechanical release combined with an immediate chemical release (MC): the mechanical release (same as for "M") was followed by directed spray application with a backpack sprayer of a 50% triclopyr ester (Garlon): water mix to all of the cut stems,

(3) mechanical release combined with a delayed chemical release (MC2): the mechanical release (same as for "M") was followed by a directed spray application of a tank mix of 0.0009% Sulfometuron methyl (Oust) and 2.5% glyphosate (Accord) in the following growing season (June of 2000),

(4) mechanical release combined with both a chemical release and a fertilization treatment (MCF): the mechanical release (same as for "M") and the triclopyr ester chemical release (same as for "MC") with diammonium phosphate in granular form at a rate of 68 kg N per acre and 23 kg P per acre applied by hand across the cleared area (created by the mechanical release),

and

(5) control (Control): no treatment.

In 2002, five growing seasons after the treatments, the trees in the M, MC2, and MCF categories were each fertilized with 383 g of N (as urea) hand broadcast in granular form around the area within 1.8 meters of each tree. This was done to increase the potential for examining the effects of fertilization within this study area.

Data Collection

The diameters (± 0.3 cm) at breast height of all trees were measured by diameter tape in 1998 at the time of treatment installation, and again in 2001, 2004, and 2010 (begun in December 2009). The total height of each tree was measured in 1998 at the time of treatment installation (by telescoping height poles, ± 0.2 m), and in 2001, 2004, and 2010 (by Vertex IV BT Hypsometers, ± 0.2 m).

Height to live crown was measured in 2010 (by Vertex IV BT Hypsometers, ± 0.2 m). One of three classes of epicormic branching was also designated for a subset of the study trees at this time. The epicormic branching categories were:

1. clear from base to crown or few (≤5) branches 13 cm long
2. 6 -10 branches 13 - 38 cm long or 1 - 3 branches ≥ 38 cm long
3. more than 10 branches 13 - 38 cm long or more than 4 branches ≥ 38 cm long

A volume was calculated for each tree with the formula:

Volume [feet^3] = (DBH [inches])^2 x ((0.001818 x Total Height [feet]) + 0.1636) (Walters 1980)

The ground cover within a 1.8 meter radius of each tree was recorded as <25% ground cover (presence absence), 25%-75% ground cover, or >75% ground cover. The number of trees taller than 1 meter with their base in a 1.8 meter radius around each study tree was recorded. These trees were divided into two categories: those with interlaced or overlapping crowns and those that did not have crowns clearly competing for space with the trees being studied.

At three spots in each of the three stands, the heights of three dominant or codominant trees in the canopy were measured, along with the basal area at each spot.

Data Analyses

An analysis of covariance was used to examine the effects of treatments on volume when measured in 2001, 2004, and 2010, with the initial measurements taken in 1998 used as covariates. A mixed model was used to accommodate both fixed and random effects. SAS 9.2 was used for the data analyses.

A linear model was fit to the response variable to test the following hypotheses:

Treatments are not different for stimulating growth of various species
($H0: \mu1=\mu2=\mu3= \mu4=\mu5=0$)

The model was

$$y_{ijklm} = \mu + \beta X + A_i + B_j(A_i) + T_k + S_l + e_{ijklm}$$

where

y_{ijklm} was the *m*-th observation of the *i*th age, *j*th block, *k*th treatment, and *l*th species with volumes from 2001, 2004 and 2010 stacked;

μ was the overall mean;

X was the covariate (1998 volume)

β was the coefficient of the covariate

A_i was the *i*th Age of the stands (i=1,2,3);

$B_j(A_i)$ was the *j*th block effect (j=1,2,3) nested in Age;

T_k was the kth Treatment (k=Control,M,MC,MC2,MCF);

S_l was the lth Species (l=NRO,WO,YP);

e_{ijklm} was random error associated with the m-th observation of the ith age, jth block, kth treatment, and lth species with the expectations of ~ NID (0, σ^2).

Based on Akaike's Information Criteria and Bayesian Information Criteria, which indicate how well the model fits that data, the Unstructured covariance structure was chosen over the Factor Analytic, Autoregressive, and Compound Symmetry covariance structures. Differences were significant at $p \leq 0.15$.

To examine subsets of the data, an analysis of covariance with a mixed model was run for each stand and species combination with the 2010 volume as the response variable. The following model was used:

The model was

$$y_{ijklm} = \mu + \beta X + B_j + T_k + e_{ijklm}$$

where

y_{ijklm} was the m-th observation jth block and kth treatment with volumes from 2010 as the response variable;

μ was the overall mean;

X was the covariate (1998 volume)

β was the coefficient of the covariate

B_j was the jth block effect (j=1,2,3);

T_k was the kth Treatment (k=Control,M,MC,MC2,MCF);

e_{ijklm} was random error associated with the m-th observation of the jth block and kth treatment with the expectations of ~ NID (0, σ^2).

Tukey's test of significance was used to test for differences between the average 2010 volumes of each of the treatments. For the results of Tukey's test of significance, p values ≤0.1 were considered significant.

The increases in diameter and height between 1998 and 2010 were calculated, and an analysis of covariance for each stand and species combination was run with the following mixed model.

The model was (height and diameter run separately)

$$y_{ijklm} = \mu + \beta X + B_j + T_k + e_{ijklm}$$

where

y_{ijklm} was the m-th observation jth block and kth treatment with change in diameter or change in height as the response variable;

μ was the overall mean;

X was the covariate (1998 volume)

β was the coefficient of the covariate

B_j was the jth block effect (j=1,2,3);

T_k was the kth Treatment (k=Control,M,MC,MC2,MCF);

e_{ijklm} was random error associated with the m-th observation of the jth block and kth treatment with the expectations of ~ NID (0, σ^2).

Tukey's tests of significance were run on the diameter and height increases.

Tukey's tests of significance were run on epicormic branch classes, bole length, and crown length. Tukey's tests of significance were run on the number of trees within 1.8 meters of the crop trees that were competing with the crop trees for canopy space, not competing with the crop trees for canopy space, and a total of the non crop trees. For epicormic branch classes, bole length, crown length, and counts of other trees, JMP 9 was used to run the analyses and the results of Tukey's test of significance were considered significant at p values ≤0.05.

Results

Survival

Overall, survival was very high, ranging from 65% to 100% (Table 1). At age 24, survival exceeded 90% for all species in all treatments (Table 1). Across all treatments, white oaks had slightly better survival compared to the other two species, but survival was high for all species across the study.

Volume, Diameter, Height

Release from competition resulted in trees of larger volume (p=0.0711). However, the 1998 volumes, the age of the stands, and the species each accounted for more of the variation.

Although none of the 2010 yellow poplar mean volumes were larger compared to the control for any of the age and treatment combinations, one of the 2010 northern red oak volumes and four of the 2010 white oak volumes were larger than the associated controls. Northern red oak trees in the mechanical and second year chemical (MC2) release treatments in the 26-year-old stand were about 40% greater in volume than those in the control (Table 2). For white oaks, in the 20-year-old stand the MC, MC2, and MCF treatments yielded average volumes more than double that of the control. The average 2010 volume produced by the MCF treatment in the 18-year-old stand was also more than double the associated control volume (Table 2).

Some of the increases in DBH and height between 1998 and 2010 were similar in magnitude. For yellow poplar, the only treatment effect was a DBH increase of 68% greater than the control for the MC2 treatment in the 18-year-old stand (Table 3). In contrast, for the white oaks, the DBH increases were larger for the M treatment in the 18-year-old stand, and the MC, MC2, and MCF treatment in the 20-year-old stand, ranging between 43-57% larger. The increase in height was about 25% greater than that of the control for white oak in the MCF treatment in the 18-year-old stand. For northern red oak, the average DBH increase was about 45% larger than that of the control in the 18-year-old stand with the M treatment. The average height increase was about 36% and 29% larger than the control for northern red oak for the M and MC treatments respectively in the 18-year-old stand.

Epicormic Branching and Crown Length

Epicormic branching was different based on species, but not by treatment or age. There were more yellow poplars with few or no epicormic branches, and fewer yellow poplars with a high degree of epicormic branching (Table 4). For white oaks at age 20 that were given the MC, MC2, or MCF treatment (means of 4.8, 4.6, and 4.2 meters), crown lengths were greater than those of the trees in the control (mean of 2.5 meters), but bole length was not different. Crown length was also greater for 18-year-old yellow poplars in the MC2 treatment compared to those in the control (mean of 4.7 vs. 2.5 meters).

Ground Cover and Competition

Overall, no treatments spurred a flush of understory. Rather, patchy areas of higher groundcover were observed in the three forest stands. Only 38 trees out of 567 were growing amidst ground cover ≥25%. Of the 38, 22 were in the 26-year-old stand (Table 5). The control had the fewest instances of ground covers ≥25%, with only two in the 25-75% class and none in the >75% class (Table 6). The M, MC2, and MCF treatments each had 7-9 instances of ground cover ≥25%. The MC treatment had the most instances of groundcover ≥25%.

In the 18-year-old stand, the control areas had more trees within 1.8 m of the crop trees that were competing with the crop trees for canopy space than three areas out of fifteen areas of different species treatment combinations. These control areas also had more trees in the 1.8 meter radius that were not competing with the crop trees for canopy space than nine areas out of fifteen areas of different species treatment combinations.

In the 20-year-old stand, the control areas had more trees competing with the crop trees for canopy space in the 1.8 meter radius than ten areas out of fifteen areas of different species treatment combinations. These control areas had more trees that were not competing with the crop trees for canopy space in the 1.8 meter radius than the areas of all of the treatments for all species in the 20-year-old stand.

In the 26-year-old stand, the control areas had more trees competing with the crop trees for canopy space in the 1.8 meter radius than nine areas out of fifteen areas of different species treatment combinations. These control areas had more trees not competing with the crop tree for canopy space than eleven areas out of fifteen areas of different species treatment combinations.

Discussion and Conclusion

The high survival of trees in all cases was promising for the monetary value of the stands. The lack of clear improvement in survival with the treatments demonstrates how on some sites, improving survival may not be the most important goal for increasing the value of the stand. If survival had been low, finding ways to increase the number of valuable species that survived would be of greater importance. However, controlling the relative numbers of trees of different species that survive could still be an interest or a goal of a landowner. For example, yellow poplars may be preferred over oaks as crop trees if the land owner is concerned about a potential gypsy moth infestation (Johnson et al. 1998).

Improving the volume of individual hardwood trees has a huge potential for increasing their value. Although some of the treatments increased volume, most of them did not and no treatment emerged as an obvious choice for a landowner to use. Crop tree release treatments may be effective at these ages, but clearing a more extensive area around each tree may be needed for satisfactory results. Many of the similar studies used crown releases. The 1995 study by Ward of 7 to 22-year-old trees in Connecticut involved cutting all the stems within 1 meter of the crown of each crop tree, or 1 meter within the crowns of three crop trees on an 8 x 8 meter plot. This strategy effectively increased the release area relative to the size of the crop tree. The results were promising and consistent increases in the diameter of northern red oaks (and other oaks) and some temporary suppression of heights in dominant or codominant oaks. The heights of suppressed and intermediate oaks also increased. Miller (2000) also used a release based on the crown of the crop trees in a study of codominant 12 to 16-year-old northern red oaks, chestnut oaks, black cherries, and yellow poplars. One release entailed cutting all the trees in contact with the crown of the crop tree, and the second involved cutting all trees with crowns within 5 feet of the crop tree. Both of these treatments resulted in higher diameter growth. The treatment that included all trees within 5 feet of the crown of the crop tree suppressed height growth to some extent. An earlier investigation by Miller (1997) found that increased crown growing space increased diameter growth among northern red oaks from age 7 to age 80, with younger trees experiencing greater gains. A study of 4.5-year-old trees in Costa Rica showed that a release done by cutting the trees whose crowns shaded or contacted that of the crop trees consistently increased diameter growth (Guariguata 1999).

In general, large amounts of variation were observed within the data. The standard deviation for the 2010 volume in the MC treatment for the 18-year-old northern red oak was 0.042 m^3, while the mean volume was only 0.040 m^3. While this is the most extreme instance, larger standard deviations were the determining factor rather than the means in preventing more of the treatments from resulting in significantly larger volumes than the control. When presented in graphical form, the 18-year-old white oaks appear to have treatments grouped together that are larger than the control; only the MCF release is actually larger than the control (Figure 1).

The lack of an effect in epicormic branching may be further indication that the treatments were too light to have an impact. Epicormic branching is only increased sometimes with thinning or crop tree release, and it may depend on the extent of the release (Strong et al. 1995). Ward (2009) observed an increase in the number of intermediate trees that became dominant or codominant with release. Lamson and Smith (1989) observed a slower growth in the length of clear stem for released trees, but did not expect this trend to persist as the trees aged.

Ground cover was low across most of the area of the stands. It did not seem to be an important factor on these sites. With the exception of the number of trees competing with each crop tree for canopy space in the 18-year-old stand, the removal of trees from the area within 1.8 meters of the crop trees led to fewer trees within 1.8 meters of the crop tree compared to the control for the majority of treatments after the passage of 12 years. However, despite the persistence of the relatively cleared area around each tree, canopy space would not necessarily have shown a difference if it had been measured. Competition for light and space seemed just as likely from trees outside of the 1.8 meter radius around each tree than within this area. A sample of nine dominant trees in each of the three stands yielded mean heights of 15.6, 16.1, and 20.8 meters for the 18-year-old stand, the 20-year-old stand, and the 26-year-old stand, respectively (Table 8). At these heights, a cleared circle with a 1.8 meter radius offered a very limited amount of additional space. The below ground competition from all vegetation is likely to be even greater.

Although the current data from this study did not highlight a specific treatment to recommend to landowners to increase the growth of hardwoods at younger ages, research into this area should be continued. Older trees do not always respond to specific treatments on specific sites. Ellis (1979) applied crop tree release and fertilization to sugar maple (*Acer saccharum*), white ash (*Fraxinus Americana*), and black cherry (*Prunus serotina*) with an age range of 35-85 years. None of the species responded to phosphorus fertilization, black cherry responded to nitrogen fertilization with increased growth, and sugar maple responded to release with increased growth. Furthermore, even if some of the trees chosen as crop trees do not pan out as successful selections, if the crop trees as a group have a higher average volume, this may still be a desirable result for the landowner. Since we expect the larger trees in this study to continue to do better than the smaller ones within their age class, future data collected on the trees in this study may reveal additional differences between the treatments and the controls.

Tables

Table 1. The percentage of trees in each age class, species, and treatment that survived

		M	MC	MC2	MCF	Control
18-year-old stand	Yellow Poplar	93	86	100	73	88
	White Oak	100	100	93	100	94
	Northern Red Oak	84	71	65	80	83
20-year-old stand	Yellow Poplar	93	94	100	94	82
	White Oak	77	100	92	100	93
	Northern Red Oak	75	76	83	69	75
26-year-old stand	Yellow Poplar	100	100	100	100	93
	White Oak	100	100	100	100	100
	Northern Red Oak	92	93	100	100	100

Table 2. The mean volumes calculated for each treatment within each species and age class based on measurements in 1998 and 2010. Numbers in parenthesis are standard deviations.

	Volume 1998 (m^3)			Volume 2010 (m^3)		
	Age 6	Age 8	Age 14	Age 18	Age 20	Age 26
Northern Red Oak						
Control	0.0021	0.0061	0.041	0.015 (0.012)	0.027 (0.016)	0.13 (0.072) b
M	0.0024	0.0050	0.034	0.034 (0.025)	0.034 (0.024)	0.15 (0.097) ab
MC	0.0020	0.0068	0.050	0.024 (0.020)	0.040 (0.042)	0.22 (0.11) a
MC2	0.0031	0.0048	0.041	0.045 (0.044)	0.031 (0.031)	0.17 (0.081) ab
MCF	0.0030	0.0062	0.031	0.046 (0.031)	0.043 (0.037)	0.15 (0.065) ab
White Oak						
Control	0.0030	0.0057	0.037	0.027 (0.027) b	0.021 (0.014) b	0.097 (0.044)
M	0.0030	0.0044	0.046	0.046 (0.030) ab	0.032 (0.024) ab	0.15 (0.070)
MC	0.0038	0.0066	0.032	0.049 (0.039) ab	0.068 (0.053) a	0.10 (0.053)
MC2	0.0032	0.0058	0.044	0.052 (0.038) ab	0.049 (0.022) a	0.14 (0.096)
MCF	0.0031	0.0054	0.037	0.056 (0.033) a	0.053 (0.034) a	0.16 (0.13)
Yellow Poplar						
Control	0.0021	0.0065	0.034 b	0.011 (0.0074)	0.052 (0.045)	0.12 (0.067)
M	0.0025	0.0045	0.027 b	0.036 (0.035)	0.038 (0.029)	0.096 (0.046)
MC	0.0029	0.0066	0.026 b	0.032 (0.026)	0.050 (0.025)	0.11 (0.065)
MC2	0.0027	0.0054	0.050 a	0.050 (0.029)	0.046 (0.044)	0.21 (0.12)
MCF	0.0029	0.0071	0.027 b	0.038 (0.034)	0.054 (0.038)	0.10 (0.071)

Table 3. The mean DBH and Height increase between 1998 and 2010 calculated for each treatment within each species and age class

	DBH increase 1998 to 2010 (cm)			Height increase 1998 to 2010 (m)		
	Age 6-18	Age 8-20	Age 14-26	Age 6-18	Age 8-20	Age 14-26
Northern Red Oak						
Control	2.1 b	2.3	4.3	3.5 b	4.1	5.3
M	3.8 a	2.7	5.5	5.5 a	5.1	6.2
MC	3.1 ab	3.1	6.2	4.9 a	4.4	6.6
MC2	3.9 ab	2.7	5.6	5.2 ab	4.0	6.1
MCF	4.5 ab	3.3	5.7	6.3 ab	4.5	5.7
White Oak						
Control	3.1 b	2.1 b	3.1	4.6 b	3.4	4.7
M	4.8 ab	3.1 ab	4.8	5.7 ab	4.1	5.9
MC	4.6 ab	4.9 a	3.8	5.8 ab	5.1	4.3
MC2	5.0 ab	3.9 a	4.4	5.3 ab	5.0	5.3
MCF	5.4 a	4.4 a	5.4	6.1 a	5.1	5.1
Yellow Poplar						
Control	1.6 b	3.5	3.9	4.5	6.2	5.8
M	3.5 ab	3.5	3.9	5.3	5.6	5.4
MC	3.2 b	4.1	4.4	5.1	6.2	6.3
MC2	5.0 a	3.7	5.8	6.7	5.5	6.9
MCF	3.9 ab	3.9	4.0	5.4	6.2	5.2

Table 4. The number of study trees in each epicormic branch category for each species treatment combination based on a sample of 50 trees of each species. There were fewer yellow poplars in category three and more yellow poplar in category one.

	Control	M	MC	MC2	MCF
NRO in					
1	3	4	7	3	3
2	0	4	5	2	2
3	5	2	5	4	1
WO in					
1	2	5	4	6	3
2	3	4	0	1	2
3	5	5	4	2	4
YP in					
1	8	5	6	8	10
2	1	2	1	3	2
3	0	1	0	1	2

Table 5. The number of study trees in each age in each groundcover class

	<25%	25-75%	>75%
18-year-old stand	181	5	2
20-year-old stand	197	6	0
26-year-old stand	151	23	2

Table 6. The number of study trees in each treatment category in each groundcover class

	Control	M	MC	MC2	MCF
<25%	102	105	105	113	104
25-75%	2	8	12	5	7
>75%	0	1	1	2	0

Table 7. The mean number of trees within 1.8 meters of the crop trees in each of the stands for each species and treatment type, and the number of crop trees these trees are associated with. The non crop trees are divided into those that clearly compete with the crop tree for canopy space, and those that are not clearly competing with the crop tree for canopy space.

	Canopy Competing Trees			Non Canopy Competing			Crop Trees		
	NRO	WO	YP	NRO	WO	YP	NRO	WO	YP
18-year-old stand									
Control	1 a	2 a	2	12 a	10 a	10 a	10	15	7
M	1 ab	1 ab	1	7 b	9 ab	8 ab	16	12	14
MC	1 ab	1 ab	1	5 bc	5 c	6 abc	13	12	12
MC2	0 b	1 b	1	1 c	2 c	3 c	11	13	17
MCF	1 ab	1 b	1	5 bc	5 bc	4 bc	12	14	11
20-year-old stand									
Control	1 a	2 a	1 a	7 a	8 a	7 a	13	13	14
M	0 c	1 b	1 ab	2 b	3 b	4 b	12	10	14
MC	0 bc	0 b	0 b	1 b	3 b	2 bc	14	14	17
MC2	0 bc	1 b	0 b	0 b	1 b	1 c	15	11	19
MCF	1 ab	0 b	0 b	2 b	2 b	3 bc	12	12	16
26-year-old stand									
Control	1 a	2 a	1 a	6 a	7 a	7 a	11	9	13
M	0 b	0 b	0 b	3 b	3 b	4 ab	11	12	13
MC	0 ab	0 b	0 b	1 b	1 b	2 c	13	11	14
MC2	0 ab	0 b	0 b	0 b	1 b	0 c	10	10	14
MCF	0 ab	0 b	0 b	1 b	2 b	2 bc	11	12	12

Table 8. The mean height of nine dominant trees and the mean of three of basal areas measured at three locations in each of the three stands

Stand Age	Dominant Tree Height (m)	Basal Area
18	15.6	9.7
20	16.1	13
26	20.8	11

Figures

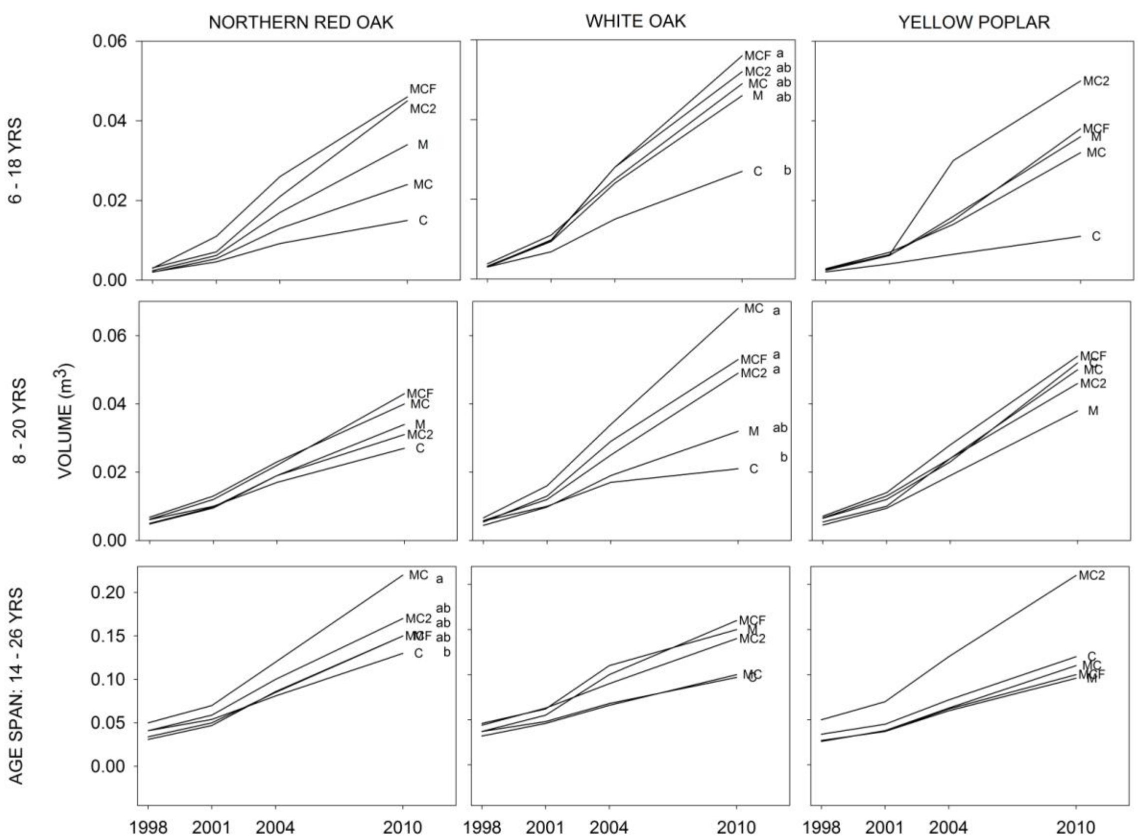

Figure 1. The mean volumes for each treatment by age, class, and species. The 18-year-old white oaks, the 20-year-old white oaks, and the 26-year-old northern red oaks show treatments resulting in significantly larger volumes than the control.

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