COMPETITION CONTROL IN MID-ROTATION LOBLOLLY PINE (*Pinus Taeda* L.)

STANDS

By

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Woody competition during mid-rotation limits available nutrients to crop species. Mid-rotation competition control was evaluated to determine if applications would result in significant increase in growth. Two studies were initiated using herbicides and prescribed burning on mid-rotation loblolly pine plantations. The first study contained afforested stands in Mississippi. Combination of imazapyr and burn was applied. The second study contained reforested sites in Mississippi. Treatments consisted of imazapyr and burn, imazapyr only, burn only, and a control. Five-year post-treatment measurements for the first study showed no significant treatment differences in height, diameter, basal area, or volume growth. Nine-year post-treatment measurements for the second study showed no significant differences in growth using the same measurements. Although previous research has documented significant growth responses to mid-rotation competition control, results from this study demonstrate that increased growth does not always result from mid-rotation competition control, suggesting initial site conditions may dictate degree of response.

ACKNOWLEDGEMENTS

I would like to first off thank my major professor Dr. Ian Munn for the opportunity to be a part of this project. I would have not been able to receive my Master of Science in Forestry without this chance. I would also like to thank both of my committee members Dr. Scott Roberts and Dr. Donald Grebner for all the help along the way they have both given me. I would not have completed my statistical analysis without the help and patience of Dr. Scott Roberts. A special thanks to Dr. Andrew Ezell for all he has done for me throughout this project. I would also like to thank Dr. Rick Kaminski because without his initial help I may never have arrived at Mississippi State seeking a Masters degree. I would like to thank Nathan Traywick, Landis Herrin, and Ryan Winters for all their help doing field work.

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# CHAPTER I

# INTRODUCTION

Forest landowners often use various silvicultural tools to maximize financial returns from their timber. Prescribed burning and herbicide treatments for controlling competition throughout the rotation have been used in pine plantations to increase stand growth and ultimately improve financial returns. Mid-rotation, which is the period following the establishment period of the stand extending to, but not including, the final harvest, specifically can be an opportunity to control competition and potentially influence stand growth. Mid-rotation stand growth can be restrained by woody or herbaceous vegetation, limiting the amount of available resources to the crop species (Shiver and Brister 1996). Reducing competing vegetation results in increased nutrient availability allowing increased pine stand growth (Fortson et al. 1996, McInnis et al. 2004, Pienaar et al. 1983). Any increase in pine growth can increase the total amount of merchantable volume. If merchantable volume increases, competition control may be financially profitable (Caufield et al. 1999). Mid-rotation competition control has often been used in loblolly (*Pinus taeda* L.) pine plantations with the intent to increase volume growth (Caufield et al. 1999).

In many mid-rotation studies, herbicide treatments have resulted in increased tree growth through removal of competition (Albaugh et al. 2003, Fortson et al. 1996, Pienaar et al. 1983, and Quicke and Minogue 2003). Pienaar et al. (1983) used glyphosate herbicide treatment in nine to fifteen-year old site-prepared slash pine (*Pinus elliottii*

Englem.) plantations to eliminate understory vegetation, resulting in increased diameter at breast height (d.b.h.) and height growth four years post treatment relative to untreated plots. Fortson et al. (1996) observed similar results, as well as an increase in basal area per acre, tree volume per acre, and merchantable volume per acre with a glyphosate herbicide treatment in mid-rotation site-prepared loblolly pine plantations age five to nine and twelve to sixteen measured eight years post treatment. Other studies have also reported increases in total pine volume as a result of mid-rotation herbicide treatments in loblolly pine stands (Albaugh et al. 2003, Quicke and Minogue 2003). Several other studies have also reported an increase in both height and diameter growth when herbicides were used at mid-rotation (Bacon and Zedaker 1987, Cain 1991, Creighton et al. 1987, Jokela et al. 2000, Knowe et al. 1985, Miller et al. 2003, Zutter and Miller 1998). In two to seven year-old loblolly, slash, and longleaf (*Pinus palustris* Mill.) pine plantations, herbaceous vegetation control using herbicides resulted in increases of both height and diameter growth (Creighton et al. 1987). Knowe et al. (1985) reported an increase in diameter, height, and volume four years after herbicide treatments in a loblolly pine plantation. Significant volume responses were seen five and eight years post-treatment when an herbicide treatment was applied to reforested pine plantations (Jokela et al. 2000). Miller et al. (2003) found increased height, diameter, and merchantable volume growth at age fifteen when herbicide treatments were used in the first three to five years of growth. A reforested pine plantation three years post treatment showed a significant increase in diameter and volume growth with competition control (Bacon and Zedaker 1987). At age eleven, significant height, diameter, and stand volume growth responses at age eleven were recorded on reforested sites (Zutter and Miller 1998). Cain (1991) found significantly greater diameter and volume growth five years after herbicide treatment on naturally regenerated loblolly and shortleaf pines (*Pinus enchinata* Mill.).

The increase in pine growth may be a result of increased availability of limiting resources. Soil moisture can be a limiting factor in pine growth. In such cases, removal of competition for available water will increase the amount of water available for the young pines (Knowe et al. 1985).

Competition control can also be accomplished using prescribed burning during mid-rotation. Prescribed burning can reduce competition for water and nutrients in pine stands, resulting in increased tree growth (Johansen 1975, Crow and Shilling 1980). Prescribed fire may also reduce loss from certain diseases, thin overly dense young stands, make working in an area cheaper and easier, and reduce fuel loads (Crow and Shilling 1980). Improved soil fertility may result from prescribed burning, increasing the available amounts of phosphorus, calcium, and magnesium (Johansen 1975). An increase in available nutrients with reduced competition for these resources would be advantageous to pine stands. Some studies have observed an increase in diameter and height growth after mid-rotation prescribed burning (Johansen 1975, Lillieholm and Hu 1987, Villarrubia and Chamber 1978). Johansen (1975) found an increase in both the d.b.h. and total height following a prescribed burn in nine-year-old slash pine in Georgia. While some studies have reported increased growth (Johansen 1975, Lillieholm and Hu 1987, Villarrubia and Chamber 1978), others have reported no significant growth or reduced growth following burning, possibly due to excessive crown scorch (Lillieholm and Hu 1987, Waldrop and Van Lear 1984).

The combination of herbicides with prescribed burning has also been reported to significantly reduce the amount of competing vegetation in young pine stands (Shiver and

Brister 1996). Herbicides in combination with prescribed burning treatments have resulted in increases in both height and diameter growth in mid-rotation pine plantations (McInnis et al. 2004). However, few studies have examined the growth response in mid-rotation pines to competition control on reforested sites using herbicide treatments and prescribed burning together, and no studies of this treatment on afforested sites have been done. Competition control on afforested sites needs further research. Hardwood competition on afforested sites differs greatly from reforested sites. Hardwood rootstocks and seed banks are abundant on reforested sites but not so on afforested sites.

Competition control on afforested sites also needs to be addressed because of its impact on Conservation Reserve Programs (CRP). Currently, CRP allows cost-sharing for competition control treatments on these sites under the Quality Vegetation Management (QVM) treatment using Arsenal Applicators Concentrate® (Arsenal AC) and prescribed burning (Mississippi, EFOTG practice standard MS-ECS-645-12). However, there has been no research to determine if this treatment will increase growth and merchantable volume on afforested CRP sites. The return on investment of competition control on afforested sites should be assessed if competition control on land enrolled in CRP continues to be promoted through cost-share.

The combination of fertilization and mid-rotation competition control is another silvicultural option available. Fertilization is another treatment that can be used during mid-rotation to enhance growth of a pine plantation (Stearns-Smith et al. 1992). Fertilization has become a common silvicultural practice among industrial landowners throughout the South. However, the effect of fertilization when combined with mid-rotation competition control is not well studied. Fertilization could potentially mask or even adversely affect any growth response due to competition control. McInnis et al.

(2004) found that when fertilization was used in combination with vegetation control in mid-rotation loblolly pine stands there was no additive effect due to the treatment. The fertilization increased growth irrespective of any competition control treatments. Therefore, the interaction of fertilization in combination with competition control must be understood if the two treatments are to be combined.

Two ongoing studies are evaluating the effect of mid-rotation competition control through the combination of herbicide treatments and prescribed burning on loblolly pine growth and volume production. One study was installed on afforested land enrolled in CRP in Mississippi (hereafter - the CRP study). Research on the effectiveness of mid-rotation competition control on afforested sites, where pre-existing sources of hardwood completion, such as rootstock and seed stored in the soil bank are absent, is lacking. Specifically, the purpose of this study was to assess the growth response to “QVM” treatments allowed under CRP in mid-rotation plantations. Following the guidelines outlined under CRP for treatment cost share, a combination of herbicide and prescribed burning was used to eliminate woody competition in loblolly pine stands ages ranging from 15 to 18 years. An earlier assessment showed that at two years post treatment no significant growth or volume response was evident (Sladek 2006); however, several studies have shown that the response to mid-rotation competition control may be delayed, not becoming significant until four years or more following treatment (Pienaar et al. 1983, Shiver et al. 1983, Oppenheimer et al. 1989).

The second study, located on industrial lands near Scooba, Mississippi, (hereafter - the kemper county study) compared herbicides, prescribed burning, and a combination of herbicide and prescribed burning, to control competition. The site was inadvertently fertilized in the spring of 2001, which was the beginning of the second growing season following the treatment (Smith 2004). The study site contained four 20- to 24-year-old reforested loblolly pines stands. The efficacy of herbicide treatment and prescribed burning in combination has not been thoroughly assessed in the literature and is addressed in this study. The effect of fertilization in conjunction with competition control is also not well understood, and even though fertilization was not a planned component of this study, it must be considered in the analysis of the results. A previous analysis (Smith 2004) showed that at two years post treatment, no significant growth or volume response was evident.

Several studies have suggested that significant treatment responses may not be detected immediately (Pienaar et al. 1983, Shiver et al. 1983, Oppenheimer et al. 1989). On nine to fifteen year old slash pine plantations, significant growth was not recorded until four years post treatment (Pienaar et al. 1983). On loblolly pine stands ranging in ages five to nine years and twelve to sixteen years old, Shiver et al. (1994) observed a significant growth response after four years post treatment using both individual tree measurements as well as stand level calculations similar to the calculations used in this study. Oppenheimer et al. (1989) observed similar results on nine to fifteen year old slash pine plantations. Ten years post treatment, the treatment increased height, basal area, total and merchantable volume growth per tree and per hectare. In summary, significant growth response to mid-rotation treatments is often delayed for several years. Therefore, the reexamination of these two studies will be done five to nine years post treatment to see if a delayed treatment response was evident.

The objectives of this study are to evaluate post treatment growth for the CRP and kemper county projects. The use of mid-rotation competition control has not been studied on afforested pine sites. The effect of competition control on an afforested site may be different than on reforested sites. Competition on afforested may not be severe enough to warrant the use of competition control on these sites. Therefore, if timber growth is the main goal then competition control may not be warranted. There is also little research on using a combination of both herbicide and prescribed burning during mid-rotation of pines. This combination treatment has not been well studied to see if it will significantly reduce competition and in turn increase timber or volume growth. A return on investment must then be seen from the increase in volume growth for this treatment to be economical. This study will assess if mid-rotation competition control using the methods described above increases timber growth or volume increase on afforested and reforested sites.

CHAPTER II

METHODS

## CRP Study

### Study Area and Treatment

This study originally consisted of twelve study sites. Due to extenuating circumstances (unintentional disking, escaped prescribed fire, tornado, etc.) only 9 study sites were available for measurement two years post treatment. By five years post treatment, only six sites remained, consisting of study sites in Kemper, Neshoba, Lincoln, and Covington counties of east central and southern Mississippi. The study sites are 18.2 ha of privately owned, afforested mid-rotation loblolly pine plantations that were 15-18 years of age at the initiation of the study. The major competing specie on all 6 sites was Chinese privet (*Ligustrum sinense* Lour.). The stands at each study site were established through the Conservation Reserve Program.

Two treatments were applied at each study site, a control and a herbicide application combined with a prescribed burn. This practice has been labeled quality vegetation management (QVM) by the NRCS as an approved mid-rotation treatment in Mississippi (Mississippi, EFOTG practice standard MS-ECS-645-12). The herbicide, Arsenal Applicators Concentrate® (Arsenal AC), was applied in the fall of 2002. The herbicide treatment was a mixture of 1169 ml $ha^{-1}$ (16.0 oz $ac^{-1}$) active ingredient imazapyr at a mix rate of 75.7 l $ha^{-1}$ (8.1 gallons of water per acre). The prescribed burns were applied during the winter of 2002-2003.

The QVM treatment was randomly assigned to one of two 8.1 ha treatment plots at each of the remaining six study sites (block). The remaining plot at each study site served as the control. Within each of the plots, nine 0.02 ha measurement sub-plots were established. The study is a completely randomized block design. The plots were remeasured in winter of 2007-2008 to determine the five year post-treatment response.

Nine fixed 0.02 ha measurement sub-plots were established per treatment plot on an 80 x 101 meter spacing to account for minor site variations across the treatment plots. All trees >12.7cm d.b.h. in the 0.02 ha sub-plots were marked with an aluminum tag at breast height (1.37m). Stem diameter at breast height (DBH), measured directly above the aluminum tag, total height (TH), and total merchantable height (MH = height to 7.6cm top, quality permitting) were measured before the first growing season following treatment and also in dormant seasons of 2003-2004 and 2004-2005.

In November 2003 – March 2004, non-merchantable hardwood and woody shrub stem counts were conducted. At the center of each 0.02 ha sub-plot, a 0.004 ha circular plot was established. All non-merchantable hardwood and woody shrub stems were counted and recorded by species. Total stems per hectare of all hardwood and woody shrub stems and total basal area per hectare for all hardwood and woody shrub stems were then calculated from plot data.

DBH, TH, and MH were measured and recorded for all trees on each 0.02 ha measurement subplot in the winter of 2008. Initial individual tree heights were subtracted from five-year post treatment heights to provide height growth over the study period.

Diameter growth was computed as the difference between the initial stand level quadratic mean diameter (Dq) and the fifth year stand level Dq. For each tree in the measurement plot, basal area per tree ($meters^2$) was calculated. The basal area per tree was summed for all trees in the measurement plot and converted to basal area per hectare.

**Stand Volume**

Total and merchantable cubic foot stem volumes for each tree were calculated using Merrifield and Foil (1967) volume equations:

$$\text{Volume (TH)} = -1.506 + 0.5162(DBH) + -0.0265(Ht) + 0.0018(DBH)^2(Ht)$$

$$\text{Volume (MH)} = -1.5158 + 0.4811(DBH) + .0.01207(Ht) + 0.002087(DBH)^2(Ht)$$

(Eq. 1)

DBH = Diameter at breast height (inches)

Ht = Appropriate (total or merchantable) height of stem (feet)

Plot volumes (total and merchantable) were computed by summing individual tree volumes within each plot and then using the average volume per plot across the site. Plot volumes ($ft^3$ per plot) were converted to cubic meters per hectare ($m^2ha^{-1}$). The five-year growth response was then computed as the difference between the fifth year volumes per hectare and the initial volumes per hectare.

**Statistical Approach**

Analysis of variance (ANOVA) using a general linear models (GLM) approach was used to test if initial stand measurements differed between sites and plots as well as growth differed significantly between treatments, sites, and plots. (SAS 9.1, SAS Institute, Inc., Cary, NC). Response variables analyzed included stand average increments in diameter, basal area, volume (merchantable and total), and height (merchantable and total). Significance was determined based on paired t-test using a critical value of $\alpha \leq 0.05$.

## Kemper County Study

### Study Area and Treatment

The study is located on industrial forest land located in Kemper County, Mississippi in the Interior Flatwoods of the Upper Coastal Plain (Shultz 1997, Hood 2001, Smith 2004). The test sites were four loblolly pine plantations ranging from 18-22 years of age at study initiation. The test sites were thinned two to five years before the study began and then fertilized in 2001 after the thinning.

The major competing species in all four sites before treatment were: sweetgum (*Liquidambar Styraciflua* L.), red maple (*Acer rubrum* L.), oaks (*Quercus* spp.), hickories (*Cayra* spp.), black gum (*Nyssa sylvatica* L.), shining sumac (*Rhus copilina* L.), poison ivy (*Rhus toxicodendron* L.), and blackberry (*Rubus* spp.).

There were four 30-40 ha sites designated for this study, which were each divided into four 7-10 ha treatment plots. The four treatments were the control (C), prescribed burn (B), herbicide application (H), and prescribed burn plus herbicide application (BH). Treatments were randomly applied to one of the four treatment plots at each site giving the study a completely randomized block design. Each treatment plot contained a 40m by 40m measurement plot consisting of 30-55 trees per plot. All trees within the measurement plots were tagged with an aluminum identification number. Arsenal® (BASF Corporation, Mount Olive, NJ) was applied in the fall of 1999 for both H and BH treatments. The herbicide was applied at a rate of 697-872 ml $ha^{-1}$ (9.6-12.0 oz $ac^{-1}$) active ingredient imazapyr at a mix rate of 150-187 l $ha^{-1}$ (16-20 gallons of water per acre), with 0.5% Timbersurf 90® surfactant (Timberlands Interprise, Inc., Monticello, AR). Burning for both B and BH treatments were completed in the winter of 2000.

In the early summer of 2001 one year post treatment, woody competition was characterized (Smith 2004). For all treatments, the number of live woody stems per hectare and basal area per hectare in the < 5cm DBH class was significantly less than the control.

**Stand Volume**

Nine year post-treatment measurements from the 40m by 40m measurement plot for each treatment plot were taken in early spring of 2009. All timber growth and stand volume growth calculation procedures are the same as discussed for the CRP study.

**Statistical Approach**

An Analysis of Variance (ANOVA) using a general line models (GLM) approach was used to test whether or not the treatment responses differed significantly from one another (SAS 1999). Response variables analyzed included nine year growth (volume, height, basal area, and diameter). Significance was determined based on a critical p-value of $\alpha \leq .05$

# CHAPTER III

# RESULTS

## CRP Study

### Hardwood and woody shrub competition

The hardwood and woody shrub vegetation one year post-treatment was significantly lower in the QVM treatment than in the control treatment based on total hardwood and woody shrub stems per hectare ($P = 0.0004$), total understory hardwood and woody shrub basal area per hectare ($P = 0.0036$), and total hardwood and woody shrub basal area per hectare ($P = 0.0076$). The mean number of hardwood and woody shrub stems per hectare was reduced by 69 % from a mean of 7239 stems per hectare on control plots to 2212 stems per hectare on QVM treated plots (Figure 1). Mean understory hardwood shrub basal area was 3.39 $m^2ha^{-1}$ on control plots and 0.94 $m^2ha^{-1}$ on QVM treated plots. Mean total hardwood shrub basal area was 3.53 $m^2ha^{-1}$ on control plots and 1.16 $m^2ha^{-1}$ on QVM treated plots (Figure 2).

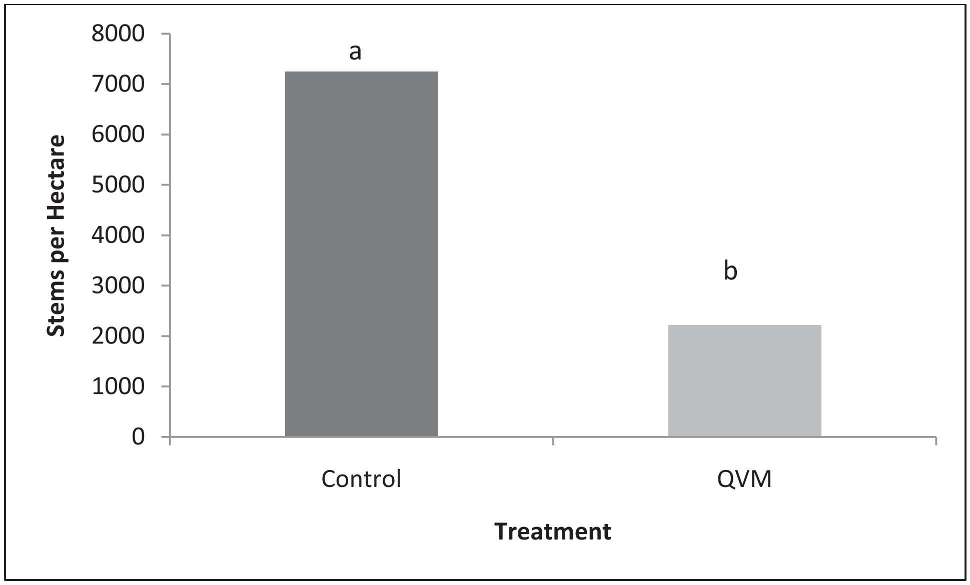


Figure 1 Comparison of mean total stems per hectare for all treatments and the control (means followed by the same letter are not significantly different).

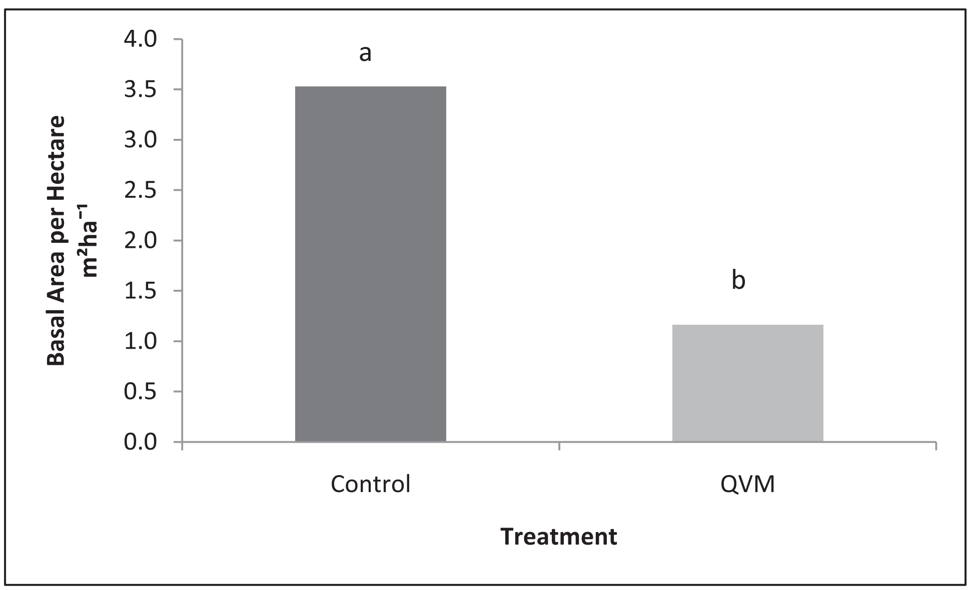


Figure 2 Comparison of mean total hardwood shrub basal per hectare for all treatments and the control (means followed by the same letter are not significantly different).

## Stand Growth and Volume

Two years post-treatment there were no significant growth differences between treated plots and control plots for any of the measurements including Dq, height, basal area, or total volume growth (Sladek 2006). At five-years post-treatment, there were still no significant differences in mean total height growth ($P$ = 0.2589), mean merchantable height ($P$ = 0.3373), mean dbh ($P$ = 0.9247), mean total height volume growth ($P$ = 0.5795), and mean merchantable height volume growth ($P$ = 0.4269) between the QVM and control treatments. The mean total height growth for the control and QVM treatments was 1.07 m per year and 1.01 m per year, respectively (Figure 3). The mean merchantable height growth was 0.97 m per year and 0.85 m per year for the control and QVM treatments, respectively. The mean total height volume growth for the control and QVM treatments was 19.83 $m^3$ per hectare per year and 21.07 $m^3$ per hectare per year (Figure 4). The mean merchantable height volume growth for the control and QVM treatments was 20.38 $m^3$ per hectare per year and 18.92 $m^3$ per hectare $^3$ per year. The dbh growth for the control and QVM treatments were 1.17 cm per year to 1.17 cm per year, respectively (Figure 5). The basal area growth for control and QVM was 1.73 $m^2$ per hectare per year to 1.80 $m^2$ per hectare per year, respectively (Figure 6).

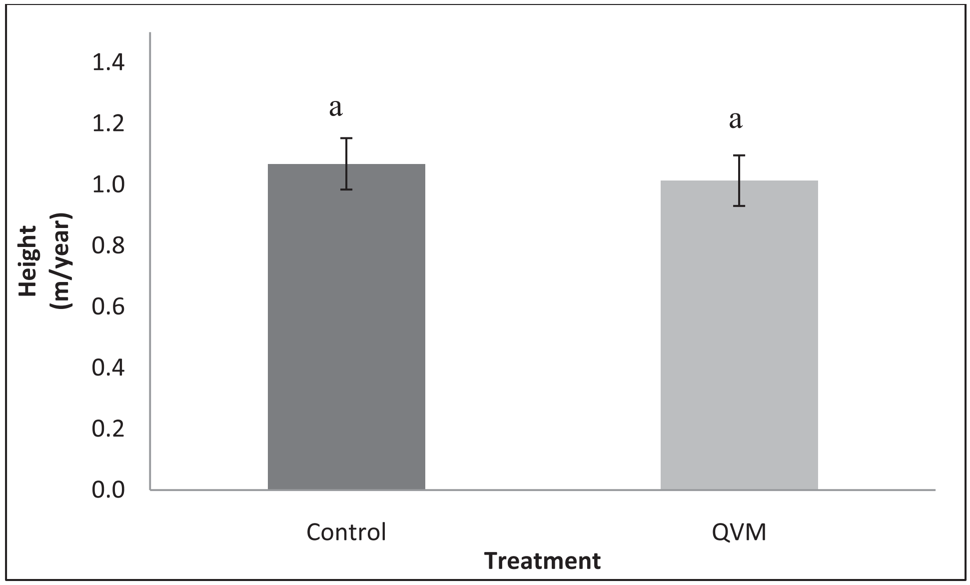


Figure 3 Comparison of mean height growth per year between the control treatment and QVM treatment (means followed by the same letter are not significantly different).

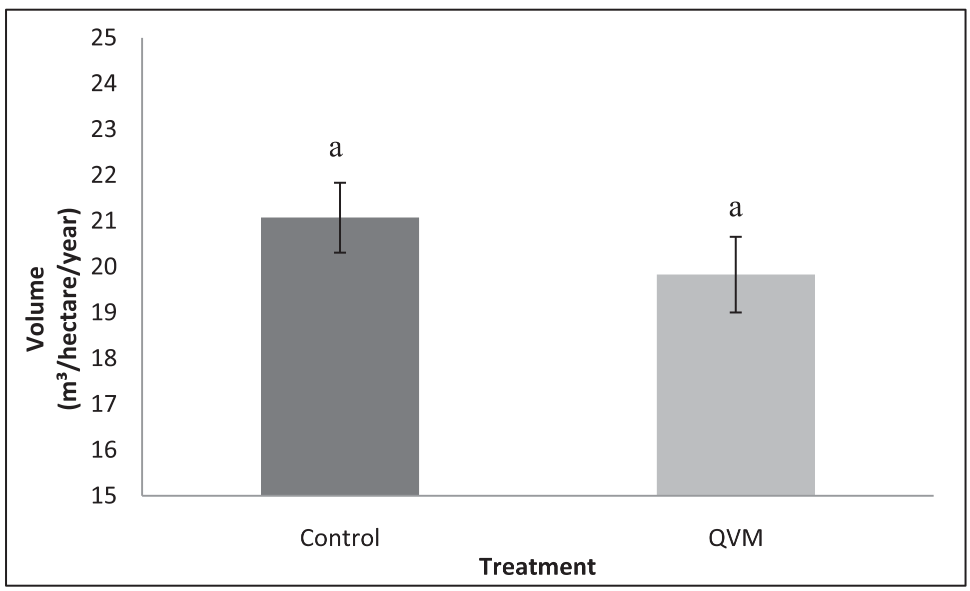


Figure 4 Comparison of total volume growth per year between the control treatment and QVM treatment (means followed by the same letter are not significantly different).

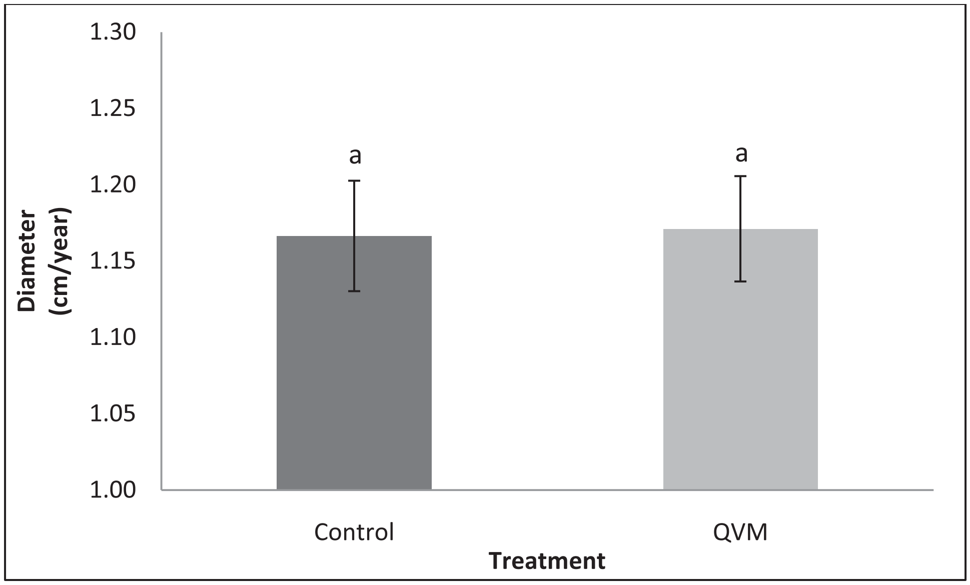


Figure 5 Comparison of mean diameter growth per tree between the control treatment and QVM treatment (means followed by the same letter are not significantly different).

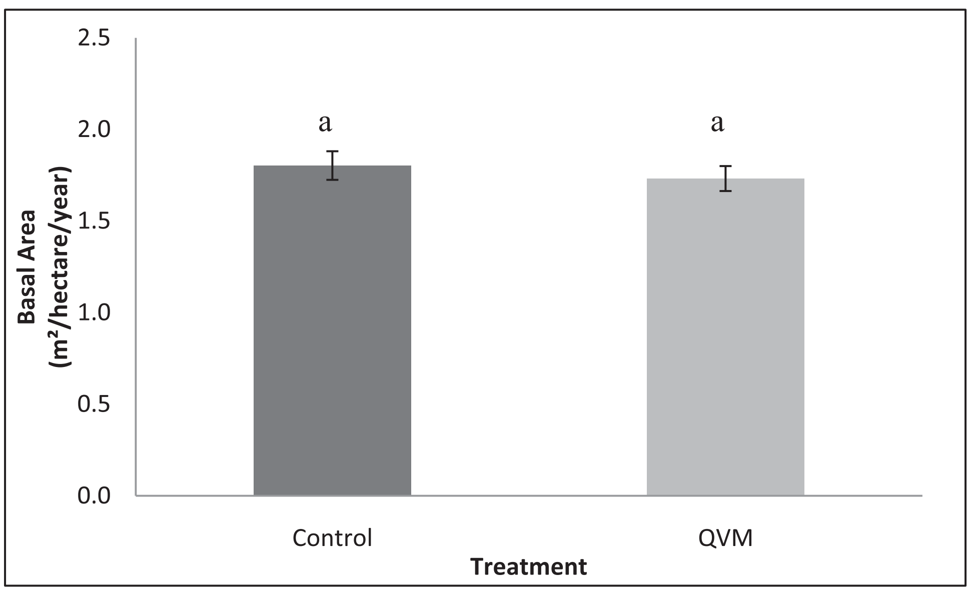


Figure 6 Comparison of basal area growth per hectare per year between the control and QVM treatments (means followed by the same letter are not significantly different).

## Kemper county Study

### Hardwood and woody shrub competition

The hardwood and woody shrub vegetation two years post-treatment were significantly lower for all treatments compared to the control treatment based on live woody stems per hectare <5cm DBH class and woody competition basal area in the <5cm DBH class. The average number of woody stems per hectare and basal area in the >5cm DBH class was not significantly different among treatments. The mean live woody stems per hectare <5cm class for each treatment was C (3250) > B (1606) > H (406) = BH (231) (Figure 7). Average total basal area per hectare in the <5cm class was 1.13 $m^2ha^{-1}$ for C, 0.41 $m^2ha^{-1}$ for B, 0.20 $m^2ha^{-1}$ for H, and 0.09 $m^2ha^{-1}$ for BH (Figure 8).

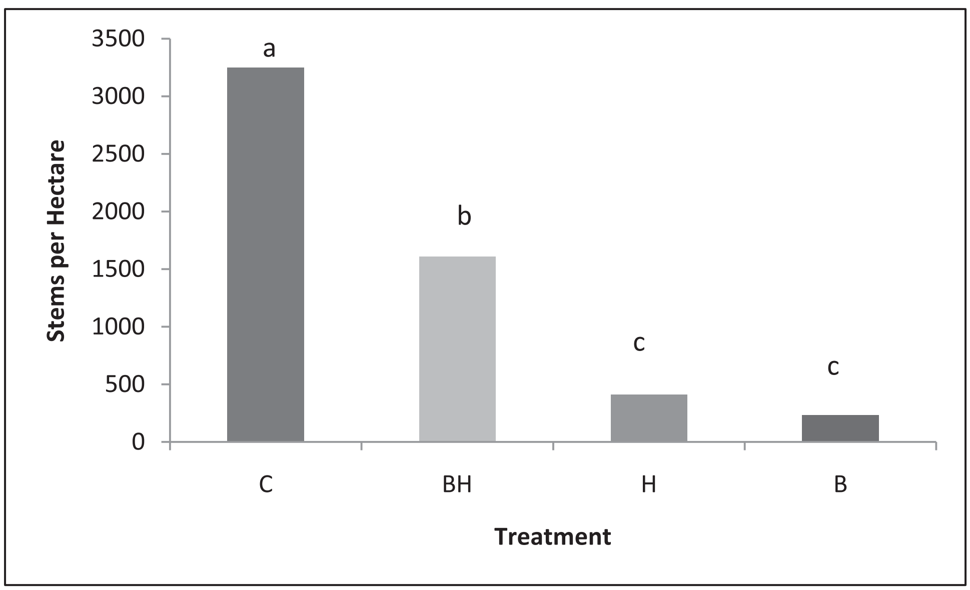


Figure 7 Comparison of mean total stems per hectare <5cm DBH class for all treatments and the control (means followed by the same letter are not significantly different).

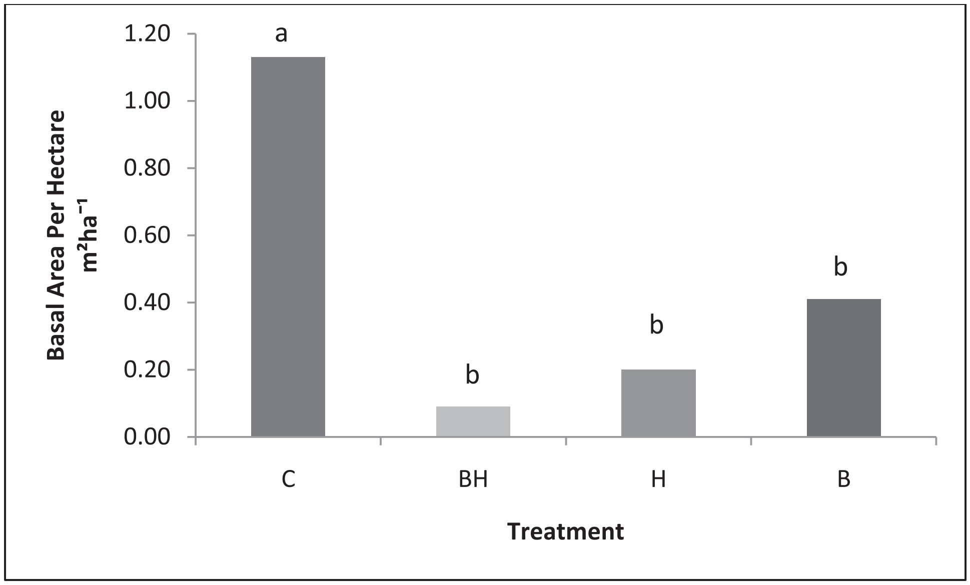


Figure 8 Comparison of mean basal area of total woody understory vegetation per hectare <5cm DBH class for all treatments and the control (means followed by the same letter are not significantly different).

**Stand Growth and Volume**

There were no significant differences in 1999 between any of the study areas based on pre-treatment stand measurements. Stand density averaged 250 trees per hectare (TPH), mean DBH averaged 26.9cm, mean height averaged 18.5m, and mean BA averaged 15.1m²/ha (Smith, 2004). Height, diameter, and volume growth did not differ significantly between any treatments and the control two-years post treatment. For a more complete description of the methods and results, see Smith (2004).

There were no significant differences in mean growth for height, volume, and basal area between the treatments BH, B, H and the control nine years post-treatment. Mean total height growth ($P$ = 0.9034), mean total volume growth ($P$ = 0.5026), and mean basal area growth ($P$ = 0.1052) were not significantly different among treatments (Figures 9,10, and 12). However, diameter growth was significantly different ($P$ = 0.0414) among treatments. Diameter growth for treatment H was significantly greater than for treatments B and BH, but none were significantly different from the control (Figure 11).

Mean height growth nine years post treatment ranged from 0.70 m per year (treatment H) to 0.73 m per year (treatment B) (Figure 9). Mean volume growth ranged from 15.43 $m^3ha^{-1}yr^{-1}$ to 16.20$m^3ha^{-1}yr^{-1}$ with BH being the largest and H being the smallest (Figure 10). The range in diameter growth across all treatments was from 1.21 cm per year to 1.39 cm per year, with B being the smallest and H being the largest (Figure 11). The range in basal area growth for all treatments was 1.42 $m^2$ $ha^{-1}yr^{-1}$ to 1.47 $m^2$ $ha^{-1}yr^{-1}$, with C being the largest and BH being the smallest (Figure 12).

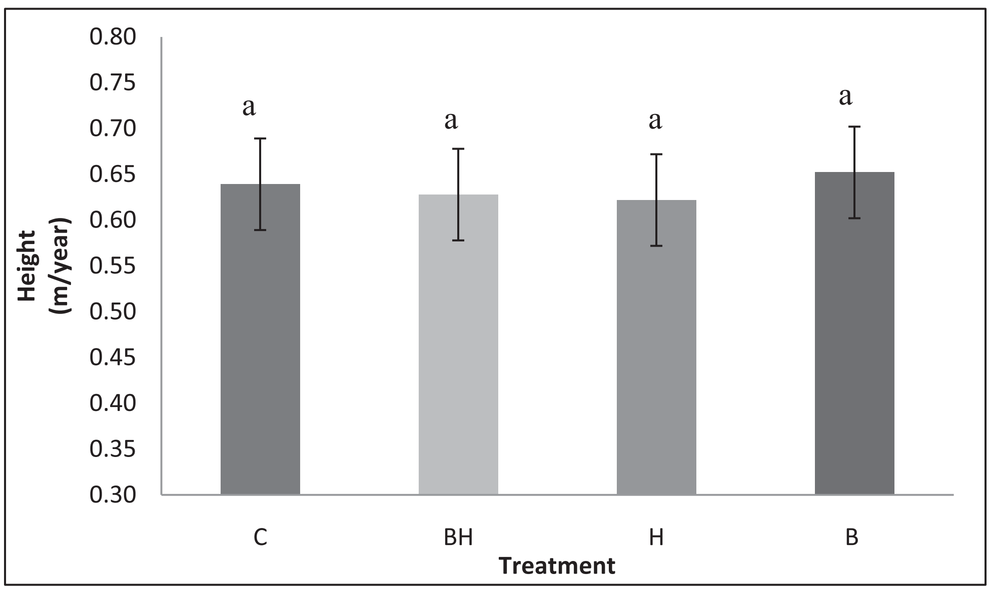


Figure 9 Comparison of mean height growth per year for all treatments and the control (means followed by the same letter are not significantly different).

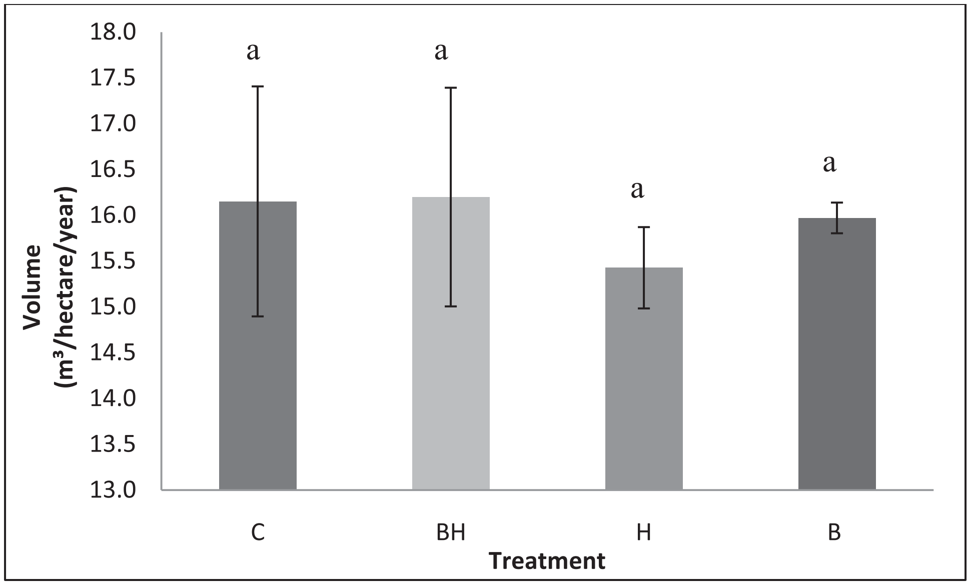


Figure 10 Comparison of total volume growth per hectare per year for all treatments and the control (means followed by the same letter are not significantly different).

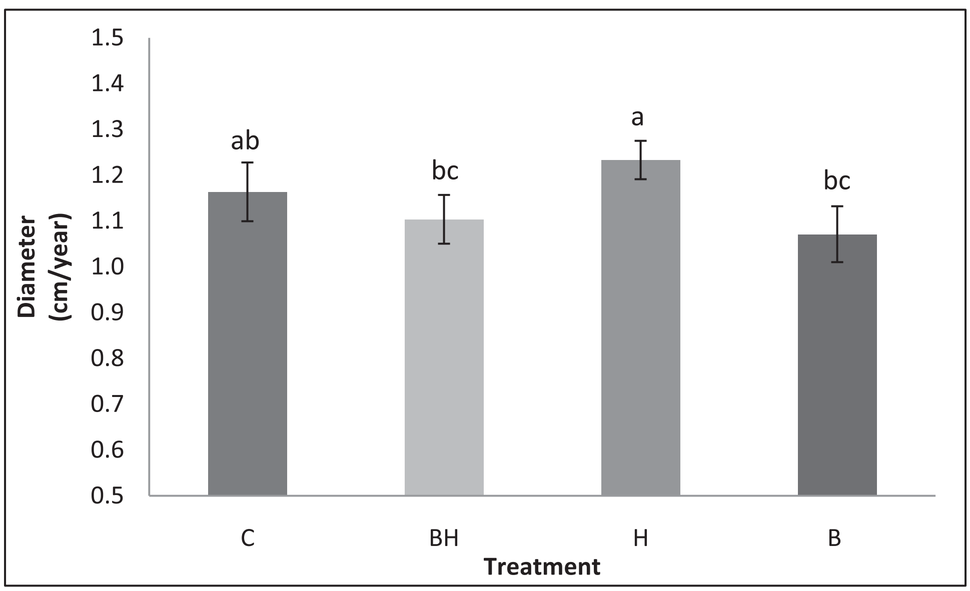


Figure 11 Comparison of mean diameter growth between all treatments and the control (means followed by the same letter are not significantly different).

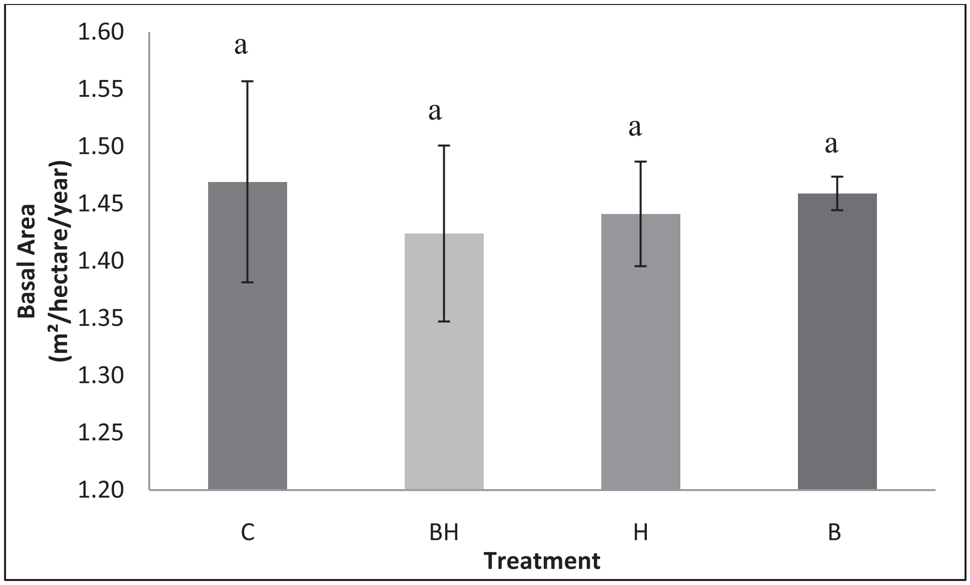


Figure 12 Comparison of mean basal area growth per hectare per year for all treatments and the control (means followed by the same letter are not significantly different)

# CHAPTER IV

# DISCUSSION

Five years following treatments in the CRP study, none of the growth response measurements (total height, merchantable height, dbh, total height volume, and merchantable height volume) were affected by the QVM treatment. Total height growth under the QVM treatments averaged 0.27 m less than under the control. For the mean merchantable height growth, QVM treatments were 0.60 m less than the control. The mean total height volume growth for the QVM treatment was 1.24 $m^3$ per hectare per year less than the control. The mean merchantable height volume growth for the QVM treatment was 1.46 $m^3$ per hectare per year less than the control. The dbh growth for the QVM treatment was 0.03 cm greater than the control.

Nine years following treatment for the kemper county study, only one of the four growth response measurements was affected by treatments. Diameter growth was significantly greater for the herbicide application than the burn and burn-herbicide treatments, but not the control. However, the other three growth response measurements (height, volume, and basal area) were not significantly greater than the control for any of the treatments. The mean height growth for the BH, B, and H ranged from 5.60 m to 5.87 m for the treatments with the control at 5.75 m of growth. The mean total height volume growth ranged from 15.97 $m^3$ per hectare per year to 16.20 $m^3$ per hectare per year for the BH, B, H treatments with the control at 16.15 $m^3$ per hectare. The basal area growth for BH, B, and H ranged from 1.42 $m^2$ per hectare per year to 1.47 $m^2$ per hectare per year with the control as the highest.

Any growth responses due to the CRP and Kemper county treatments could have been masked by several factors resulting in no significant growth response from the treatments. Possible factors that could have masked the growth response could include stands still responding from recent thinning, the fertilization in combination with the competition control, or the initial hardwood competition was not dramatically impacting the pine growth.

After a thinning takes place, the residual pine stand will attempt to fully occupy the site to fully take advantage of available resources. This results in an increased growth response for the residual trees. This increased growth response can last for several years following the thinning. Stearn-Smith et al. (1992) observed a continued response up to eight years post treatment from thinning and fertilizing treatments on southern pine stands in lower coastal plain of southeastern United States. All sites in the CRP study were all thinned within a few years of the application of the QVM treatment; however, the timing of the thinning varied for each stand. If the stands are still experiencing a growth response to the recent thinning, then the growth response due to the QVM treatment may be masked as a result. If treatment effect is masked due to thinning, the growth response will only be observed once the major growth increases from the thinning begin to slow down.

Hardwood competition in a pine stand has been confirmed on the negative impact it has on the crop pine stand. The negative impact of the hardwood competition is present from the establishment period till the end of the rotation.(Knowe et al. 1985, Creighton et al. 1987, Fortson et al. 1996). Even very small amounts of hardwood competition have been seen to affect the crop pines. The removal and control of all competing vegetation present throughout the study has resulted in significant growth responses (Oppenheimer et al. 1989, Shiver et al. 1994). Both of the studies just mentioned took place on reforested sites. Shiver et al. (1994) observed a significant growth response starting at four years post treatment using both individual tree measurements as well as stand level calculations similar to the calculations used in this study. This was observed on loblolly pine stands ranging in ages five to nine years and twelve to sixteen years old. Oppenheimer et al. (1989) observed similar results on nine to fifteen year old slash pine plantations. Ten years post treatment the treatment had an effect on height, basal area, and total and merchantable volume growth per tree and per hectare.

All sites in the Kemper county study were inadvertently fertilized one year following treatment. Any growth response due to competition control might be seen once the major growth response of the pines to the fertilization slows down. McInnis et al. (2004) found that the combination of competition control and fertilization did not have an additive effect. The fertilization resulted in increased growth irrespective of the competition control. The fertilization, therefore, might be overshadowing the results due to the competition control.

The type and location of the hardwood in the canopy may have contributed to a lack of significant growth from the QVM treatment. The majority of the competition (96%) present before treatment was below 13 centimeters in dbh and located in the understory. This type and location of competition may not be negatively affecting the growth of the existing pines.

A requirement for the CRP study was that selected stands had to be established under CRP. Consequently, these sites were all afforested agricultural land. There was not, therefore, competing hardwood root stock or abundant hardwood seed stock present at stand establishment.  Consequently, there was little, if any, hardwood completion present in the overstory at mid-rotation. Given there was abundant hardwood competition in the mid- and understories in this study, these results suggest that competition in the overstory may be the major venue by which hardwoods impact pine growth.

# CHAPTER V

# MANAGEMENT IMPLICATIONS

Mid-rotation competition control treatments will not always result in increased growth as evident by these two studies. In two unrelated studies with site choice based on different factors, the use of competition control during mid-rotation did not show any significant growth response. There are other factors within the site interacting between the crop species and the competition that deserve to be studied further. Other site factors must be considered before applying this type of treatment such as the current hardwood species on the site, the amount of competition both between target and non-target species, and the amount of control that will be used. Managers must consider stand conditions in their decisions and be aware that every site will not have significant growth response from a mid-rotation competition control.

Mid-rotation competition control on afforested and certain reforested sites should not be used on every site if generating a positive return on investment is the objective. Although there may be a number of beneficial but non-financial outcomes to mid-rotation competition control, a positive return on investment based on increased timber values may not necessarily result. While other studies have shown a positive growth response, few have evaluated the response financially. In both studies reported here, there was no significant positive growth response to treatment so, consequently, no positive return on investment occurred.

Mid-rotation competition control will significantly reduce the amount of competition on a site, but it will not always result in significant increases in growth of the crop species.  Understanding site characteristics in relation to mid-rotation competition control as well as other mid-rotation silvicultural activities is important.  Managers must use site specific data as well as owner objectives to determine if mid-rotation competition control is a viable option.

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