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Mohammad M. Bataineh
Department of Natural Resources and Environment, Faculty of Jordan University of Science and Technology

Amanda L. Bataineh
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, Texas 75962

Brian P. Oswald
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, boswald@sfasu.edu

Kenneth W. Farrish
Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, kfarrish@sfasu.edu

Hans Michael Williams
Arthur Temple College of Forestry and Agriculture Division of Stephen F. Austin State University, hwilliams@sfasu.edu

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LOBLOLLY PINE GROWTH RESPONSE TO MID-ROTATIONAL TREATMENTS IN AN EASTERN TEXAS PLANTATION

Mohammad M. Bataineh, Amanda L. Bataineh, Brian P. Oswald, Kenneth W. Farrish, and Hans M. Williams[1]

Abstract—The effects of mid-rotational treatments (herbicide, prescribed burn, combination of herbicide and burn, and fertilization) on growth of loblolly pine were evaluated. Five replicates were established in a split-plot experimental design with fertilizer treatments as the whole-plot factor and competition control treatments as the sub-plot factor. Growth response was measured (as change in diameter, total height, and volume) at 8 months and again 4 years after treatments were applied. Mid-rotational treatments failed to enhance diameter, height, and volume growth of loblolly pine. However, a small positive response of diameter growth to fertilization was detected. Height growth was not significantly affected by any treatment 8 months after application date, while it was slightly negatively affected by herbicide and the combination of herbicide and prescribed burning 4 years after application of treatments. In this study, no substantial positive growth response to mid-rotational treatments was detected. However, loblolly growth response may vary from site to site based on differences in soil type, soil condition, and competition level. In addition, associated factors such as seedling quality and planting method may greatly influence loblolly growth response to mid-rotational treatments.

INTRODUCTION

Ideal growth potential of most southern pine plantations is not achieved. This may be attributed to low capital investments in silvicultural practices and to the uncertainty associated with future market and land ownership (Allen and others 1990). Annual volume increments of 34 $m^3 ha^{-1} yr^{-1}$ have been reported for loblolly pine (*Pinus taeda* L.) (Borders and Bailey 2001). Such annual increments were achieved using a highly intensive management approach in which complete control of competing vegetation and annual fertilization were applied throughout the study. A less intensive approach in which complete competition control was applied at mid-rotation of slash pine (*Pinus elliottii* Engelm.) plantations resulted in an increase in volume growth by 7 $m^3 ha^{-1}$ 4 years after treatment (Pienaar and others 1983).

Silvicultural practices that aim to improve availability, allocation, and amount of water and nutrients to crop trees in established-stands at mid-rotation are referred to as mid-rotational treatments. These treatments may have the potential of increasing annual volume growth and thus productivity of loblolly pine plantations. In addition, these treatments may be less capital demanding and therefore more applicable on operational management levels than complete control of competing vegetation and annual fertilization throughout the rotation. Mid-rotational treatments may include fertilization, chemical and/or mechanical herbaceous and woody competition control, prescribed burning, and thinning.

Several studies have examined the effect of fertilization and competition control on loblolly pine growth. Borders and others (2004) reported significantly greater height and diameter growth in response to fertilization and competition control. The greatest growth response was observed on the combination (fertilization and competition control) treated plots. In an earlier study, Borders and Bailey (2001) reported exceptional growth rates with mean annual increments for the combination treatments ranging between 22.6 and 34 $m^3 ha^{-1}$.

Jokela and others (2000) combined data from 21 regional experiments to examine loblolly and slash pine response to fertilization and understory competition control. The authors reported significant growth response of loblolly pine to fertilization and understory competition control as well as an additive effect of combining both treatments. In addition, Jokela and others (2000) emphasized the importance of mid-rotational fertilization to maintain growth increments that were obtained due to silvicultural treatments at establishment. Loblolly height gains in response to herbaceous control alone or woody control alone were identical in magnitude and greater than the untreated plots 11 years after treatment application (Zutter and Miller 1998). Although these studies have reported loblolly growth response to fertilization and competition control, the treatments in these studies were either applied to young loblolly stands or were applied annually throughout the study.

In 1999, a study to evaluate growth response of loblolly pine to mid-rotational treatments was established in Cherokee County, eastern Texas. Initial growth response was reported by Marino and others (2002) and Barnett and others (2002). Physiological response was reported by Goodwin and others (2004), and the effects on soil physical and chemical characteristics were reported by Wilson and others (2002). The objectives of this paper were to report loblolly pine growth response to mid-rotational treatments in the form of prescribed burning, herbicide application, combination of herbicide and prescribed burning, and fertilization 4 years after application of treatments and to compare loblolly response to data collected (from the same site) 8 months after application of treatments.

MATERIALS AND METHODS

Study Site

The study site was located within an 80 ha plantation in Cherokee County, TX (31°35' N, 94° 58' W). The site was

[1] Graduate Research Assistant, Graduate Research Assistant, and Professors of Forestry, respectively, Stephen F. Austin State University, Arthur Temple College of Forestry, SFA Station, Nacogdoches, TX 75962.

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hand-planted with improved loblolly pine seedlings (from two families: 3-050-013-CC22L2 and 172-TFS ODHM2) in 1985 at 1.8 x 3.1 m spacing. In 1998, the site was thinned to a basal area of 13 $m^2 ha^{-1}$ and density of 465 trees ha^{-1}. Soils of the study site are of the Darco (Grossarenic Paleudult), Tenaha (Arenic Hapludult), and Osier (Typic Psammaquent) series. Mean annual precipitation is approximately 114 cm, and mean annual temperature is 18 °C.

Experimental Design and Treatments

In 1999, five replications were established in a split-plot experimental design. Fertilizer treatment (fertilizer, no fertilizer) served as the whole-plot factor, and competition control treatments (herbicide application, prescribed burning, combination of herbicide and prescribed burning, and untreated control) served as the sub-plot factor. Fertilizer and competition control treatments were randomly assigned to their corresponding plots. A 10 m buffer zone surrounded each sub-plot (0.1 ha in area). Sampling plots of 0.04 ha each were centered within each sub-plot. Herbicide was applied in October 1999 as a mixture of imazapyr (Chopper®, 4.5 L ha^{-1}), glyphosate (Accord®, 2.2 L ha^{-1}), nonionic surfactant (Sun-It II®, 11.2 L ha^{-1}), and water (76.7 L ha^{-1}) using backpack sprayers. Woody vegetation > 3.7 m in height was injected with imazapyr (Arsenal®, 34 percent solution in water). Prescribed burning was accomplished in March 2000 using strip backfires. Fire temperature, relative humidity, and scorch height were measured for each burn sub-plot. In April 2000, fertilizer treatments were applied as urea and diammonium phosphate (224 kg ha^{-1} N and 28 kg ha^{-1} P) using a crank spreader.

Measurements and Statistical Analysis

The parameters evaluated included diameter at breast height (d.b.h.; 1.3 m), total height, and volume. Volume was estimated using Lenhart and others' (1987) stem content prediction model (wood and bark to upper stem). Total height was measured to the nearest 0.5 m, and d.b.h. was measured to the nearest 0.1 cm. Pre-treatment measurements were accomplished in July 1999. Post-treatment measurements were obtained in December 2000 (8 months after treatments completion) and in December 2003 (approximately 4 years after treatments completion). The two data sets were analyzed separately. In addition, height, d.b.h., and volume data were analyzed separately for each sampling period. The effects of the fixed factors (fertilizer and competition control treatments) were tested using a split-plot analysis in PROC MIXED (SAS Institute Inc. 1999). When significant interaction was revealed, multiple one-way ANOVAs were performed to test for the effect of competition control treatments (*Trt.*) at each fixed level of fertilization (*Fert.*) (Lehman 1995). In one-way ANOVAs, mean square error from the original split-plot analysis was used to obtain the *F*-statistic. In addition, Bonferroni adjustment was used to control inflation of type I error that is associated with multiple one-way ANOVAs. As a result, the effect of competition control treatments on diameter and volume growth 8 months after application of treatments was tested at an α=0.025 level. When no significant interaction was present, an α=0.05 level was used. Tukey's multiple comparison procedure was used to separate *Trt.* means whenever significant *Trt.* effect was found. A significance level of 0.05 was used to separate *Trt.* means. Mean separation output in PROC Mixed was converted to letter groupings using PDMIX800 macro (Saxton 1998).

RESULTS AND DISCUSSION

Diameter Growth Response

Eight months after application of treatments, a significant interaction between fertilizer and competition control treatments was revealed (P = 0.031). Therefore, the effects of competition control treatments were confounded by the fertilization level (fig. 1). One-way ANOVA, however, indicated a highly significant effect (P = 0.0002) of competition control treatments for the unfertilized plots at the α= 0.025 level. Mean d.b.h. growth was significantly lower for the prescribed burning treatment than for the untreated control and herbicide application (table 1). Marino (2002) quantified the scorch damage associated with prescribed burning on these plots. Lilieholm and Hu (1987) reported a short-term negative effect of crown scorch on diameter growth. Stress in the form of needle loss due to crown scorching may explain the lower diameter growth for the prescribed burned plots. Diameter growth for the untreated control was similar to that of herbicide application plots. The effects of competition control treatments on d.b.h. growth were not significantly different for the fertilized plots (P = 0.306) at the α=0.025 level. Goodwin and others (2004) reported lower photosynthetic rates, stomatal conductance, and transpiration for the fertilized plots as compared to the unfertilized plots. This lower physiological activity of fertilized plots may explain the masking effect of fertilization on competition control treatments.

Approximately 4 years after application of treatments, means of fertilizer treatments (P = 0.022) were significantly different at the α=0.05 level. Means of competition control treatments (P = 0.002) were significantly different at the same significance level. In addition, differences in mean d.b.h. growth among competition control treatments were independent of fertilization (P = 0.282). Fertilizer treatment resulted in greater d.b.h. growth than the non-fertilizer treatment (table 2). The positive response of loblolly pine to fertilization is widely reported (Borders and others 2004, Jokela and others 2000, Williams and Farrish 2000). However, diameter growth difference between fertilizer and non-fertilizer treatments was only 0.5 cm. Significantly greater diameter growth was achieved with herbicide application than with prescribed burning, suggesting a residual effect of crown scorching on diameter growth. The effect of the combination treatment (herbicide application and prescribed burning) resulted in diameter growth similar to that of prescribed burning which may suggest an advantage of using herbicide over prescribed burning as a

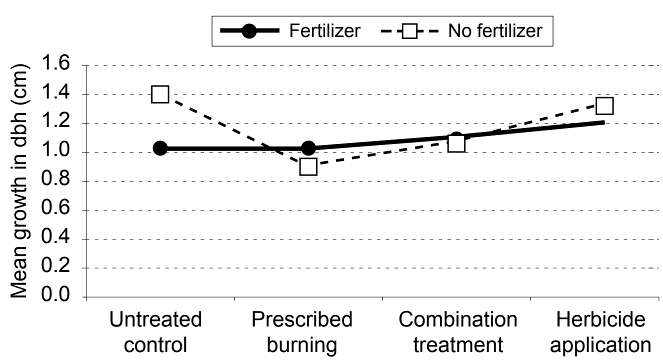

Figure 1—The confounding effect of fertilizer treatment on competition control treatments (significant interaction P = 0.031).

Table 1—Mean growth in d.b.h. (cm), height (m), and volume (m^3) of loblolly pine in response to mid-rotational treatments in the form of herbicide application, prescribed burning, combination of herbicide and prescribed burning, untreated control, and fertilization 8 months after application of treatments

Treatment	Difference in d.b.h.	Difference in height	Difference in volume
	- - - *cm*[b, c] - - -	- - - *m*[d] - - -	- - - - - *m*[3 b, c] - - - - -
Fertilized	1.1 (0.03)[a]	0.9 (0.04)a	0.039 (0.001)
Untreated control	1.0 (0.04)A	0.8 (0.06)a	0.033 (0.002)A
Prescribed burning	1.0 (0.07)A	1.0 (0.10)a	0.038 (0.003)A
Combination treatment[e]	1.1 (0.09)A	0.9 (0.08)a	0.043 (0.003)A
Herbicide application	1.2 (0.06)A	0.9 (0.08)a	0.043 (0.003)A
Unfertilized	1.2 (0.05)	0.9 (0.04)a	0.045 (0.002)
Untreated control	1.4 (0.15)a	1.0 (0.09)a	0.054 (0.005)a
Prescribed burning	0.9 (0.05)b	0.9 (0.08)a	0.036 (0.002)b
Combination treatment	1.1 (0.10)ab	1.0 (0.10)a	0.044 (0.004)ab
Herbicide application	1.3 (0.07)a	0.9 (0.07)a	0.051 (0.004)a

[a] Standard error in parenthesis.
[b] Means followed by the same capital letter within a partitioned column are not significantly different at the 0.025 level.
[c] Means followed by the same small letter within a partitioned column are not significantly different at the 0.025 level.
[d] Means followed by the same small letter within a column are not significantly different at the 0.05 level.
[e] Combination treatment = herbicide application and prescribed burning.

Table 2—Mean growth in d.b.h. (cm), height (m), and volume (m^3) of loblolly pine in response to mid-rotational treatments in the form of herbicide application, prescribed burning, combination of herbicide and prescribed burning, untreated control, and fertilization four years after application of treatments

Treatment	Difference in d.b.h.	Difference in height	Difference in volume
	- - - - *cm* - - - -	- - -*m* - - -	- - - *m*[3 b, c] - - -
Fertilized	4.6 (0.08)[a] A[b]	3.3 (0.06)A	0.193 (0.005)A
Unfertilized	4.1 (0.07)B	3.1 (0.05)A	0.178 (0.004)A
Untreated control	4.4 (0.10)ab[c]	3.6 (0.09)a	0.192 (0.006)a
Prescribed burning	4.1 (0.10)b	3.4 (0.07)a	0.176 (0.005)a
Combination treatment[d]	4.3 (0.13)b	2.8 (0.07)b	0.181 (0.007)a
Herbicide application	4.7 (0.10)a	3.1 (0.07)b	0.193 (0.006)a

[a] Standard error in parenthesis.
[b] Means followed by the same capital letter within a partitioned column are not significantly different at the 0.05 level.
[c] Means followed by the same small letter within a partitioned column are not significantly different at the 0.05 level.
[d] Combination treatment = herbicide application and prescribed burning.

mid-rotational treatment. However, variations in fire intensity, duration, and timing of prescribed burning may produce different results. In addition, mean difference between herbicide application and prescribed burning was only 0.6 cm.

Height Growth Response

Fertilizer and competition control treatments had no significant effect on loblolly height growth 8 months after application of treatments ($P = 0.790$, $P = 0.946$ respectively) (table 1), and no significant interaction was found between competition control treatments and fertilizer ($P = 0.117$) at the α=0.05 level. Four years after application of treatments, means of fertilizer treatments ($P = 0.131$) were not significantly different, whereas means of competition control treatments were highly significant ($P < 0.0001$) at the α=0.05 level. Differences in mean height growth among competition control treatments were independent of fertilization (*P* = 0.968). Mean height growth for prescribed burning was not different from the untreated control, and herbicide application was not different from combination treatment (table 2). However, herbicide application and combination treatment resulted in lower mean height growth than prescribed burning and untreated control. These results are in disagreement with Zutter and Miller (1998) who reported increases in loblolly height growth with herbaceous and woody control. Bacon and Zedaker (1987) reported no significant effect of herbicide application on height growth of young loblolly stands (3 years old). Also, no significant height growth was reported for slash pine 2 years after mechanical and herbicide treatment, but greater height growth was reported 4 years after treatment (Pienaar and others 1983). Although lower height growth was reported for the herbicide and combination treatment than for the untreated control, mean differences between these treatments and untreated control were small (0.5 and 0.8 m, respectively).

Volume Growth Response

A significant interaction between fertilizer and competition control treatments was revealed 8 months after application of treatments (*P* = 0.0004). Differences in mean volume growth (m^3) among competition control treatments were not significantly different at the α=0.025 level for fertilized plots (*P* = 0.044), whereas differences in mean volume growth among competition control treatments were significantly different for unfertilized plots (*P* = 0.0001). Mean volume growth was significantly lower for the prescribed burning treatment than for the untreated control and herbicide application (table 1). Volume growth for the untreated control was similar to that of herbicide application plots. These results are a reflection of the effect of competition control and fertilizer treatments on diameter growth. This is not surprising since that volume estimates are a combination of diameter and height measurements.

Approximately 4 years after application of treatments, means of fertilizer treatments (*P* = 0.143) and means of competition control treatments (*P* = 0.155) were not significantly different at the α=0.05 level (table 2). In addition, differences in mean volume growth among competition control treatments were independent of fertilization (*P* = 0.113). Thus, the small differences that were detected using d.b.h. and total height separately were not recognized when the two variables were combined in one variable (volume). This reinforces that differences in growth response among competition control treatments and fertilizer treatments were minute.

CONCLUSIONS

Short-term (8 months) loblolly pine diameter growth was affected negatively by prescribed burning. However, lower physiological activity (i.e., photosynthetic rate, stomatal conductance, and transpiration) due to fertilization has compensated for the negative effect of prescribed burning. A residual effect of prescribed burning on diameter growth and a small positive effect of fertilization were detected 4 years after treatment application. Height growth was not significantly affected by any treatment 8 months after application date, while it was slightly negatively affected by herbicide and the combination of herbicide and prescribed burning 4 years after application of treatments. Volume growth 8 months after application of treatments reflected the differences in diameter growth. Small differences in diameter and height growth among fertilizer and competition control treatments were concealed by the use of volume estimates 4 years after application of treatments.

No substantial positive growth response to mid-rotational treatments was detected. However, loblolly growth response may vary from site to site based on differences in soil type, soil condition, and competition level. In addition, planting associated factors such as seedling quality and planting method may greatly influence loblolly growth response to mid-rotational treatments. Mid-rotational treatments alone may not have the potential of increasing annual volume growth and thus productivity of loblolly pine plantations in eastern Texas. Other intensive approaches in which complete competition control and annual fertilization would be applied throughout the rotation might be the key for increasing productivity. However, such treatments may have a negative impact on wood quality (Borders and others 2004).

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