EFFECTS OF ANNUAL FERTILIZATION AND COMPETITION CONTROL TREATMENTS ON LOBLOLLY PINE GROWTH THROUGH AGE 25

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Abstract—Loblolly pine (*Pinus taeda* L.) plantations represent the largest surface of managed forest in the Southern United States. Over the last 3 decades, forest productivity has been increased as a result of intensive management and improved genetics. Many studies have shown the effects of fertilization and competition control in early ages (1 through 10) on yield of intensively managed loblolly pine stands. However, few studies have looked at the long-term effects of these practices on the inherent site productivity and carrying capacity. The Consortium for Accelerated Pine Plantation Studies (CAPPS), through the Plantation Management Research Cooperative (PMRC), tested if carrying capacity could be increased over the life of the stands in an experimental design with treatments of complete competition control, annual fertilization, and interaction between them. Nine study sites were distributed throughout the Piedmont, Upper Coastal Plain, and Lower Coastal Plain in Georgia, with four replications at each site and tree-level measurements collected each growing season. Results showed higher growth rates on sites receiving annual fertilization and herbicide treatments relative to the control for the first 10 to 15 years. Subsequently, growth rates for this combination treatment diminished at a greater rate than the untreated plot and competition control only. As a result, mortality rates remained fairly constant for all treatments until age 10, after which fertilized treatments showed greater annual mortality. Volume growth rates remained high for treatments without fertilization, showing no evident decline, indicating an increase in site inherent productivity.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) has been well documented as the most commercially important species of pine in the Southeastern United States. Approximately 45 million acres of established plantations exist throughout the area and an estimated 36 million of those are of loblolly origin (South and Harper 2016). In the Southeastern United States, factors that can lead to limited pine growth include site nutrient deficiencies and interspecific species competition for light and nutrients. Many planted sites use various silvicultural regimes to increase site productivity, including mechanical site preparation, competition control, fertilization, and improved genetics (Allen and others 2005, Gyawali 2015). Four treatment response patterns have been identified to best model a site's response to these different silvicultural treatments. Type A response indicates an increasing volume response with age, attributed to an increase in long-term site resources. Type B volume responses increase with age to a point, reaching an asymptotic level which are maintained through the remainder of the rotation. Type C volume responses show a temporary initial response before declining to no gain. Finally, a Type D volume response shows an initial response before resulting in a negative response (Logan and Shiver 2006). We hypothesized that type A responses should have an effect on site carrying capacity due to increases in long-term resources.

METHODS

Data Source

The Consortium for Accelerated Pine Production Studies (CAPPS) was established by the Plantation Management Research Cooperative (PMRC) to investigate volume responses to intensive silvicultural regimes. Nine study sites throughout the State of Georgia, established from 1987 to 1995, were analyzed for this study (table 1). A randomized complete block design was implemented for the experimental design. Four 0.15-ha treatment plots were established with interior 0.05-ha measurement plots in each complete block. There was a range of four to six blocks per site with up to three time establishment replicates at each site. Study sites spanned the Piedmont, Upper Coastal Plain, and Lower Coastal Plain. The initial planting density for each site was 1679 trees ha^{-1} (2.44-m by 2.44-m spacing). Four treatments, control (C), fertilization (F), competition control (H), and combination treatment (HF) were applied at the plot level (table 2). The PMRC field crew collected data annually

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Table 1—Consortium for Accelerated Pine Production Studies study site information

Site	Physiographic region	County	Soil classification	Treatments	Time replicates (number of blocks)
Athens (ATH)	Piedmont	Clarke	Pacolet/Cecil	C,H,F,HF	1989 (2), 1993 (2)
Eatonton-Monitor (BFM)	Piedmont	Putnam	Pacolet/Appling	C,H,F,HF	1988 (2), 1990 (2), 1995 (2)
Eatonton-Powerline (BFP)	Piedmont	Putnam	Cecil	C,H,F,HF	1988(2), 1990 (2), 1995 (2)
Dawsonville-Bottom (DVB)	Piedmont	Dawson	Congaree/Starr	C,H,F,HF	1987 (2), 1989 (2)
Dawsonville-Top (DVT)	Piedmont	Dawson	Hayesville	C,H	1987 (2), 1989 (2)
Thomson (THM)	Upper Coastal Plain	McDuffie	Wagram	C,H	1988 (2), 1990 (2), 1995 (2)
Tifton (TIF)	Upper Coastal Plain	Tift	Pelham/Tifton	C,H,F,HF	1988 (2), 1990 (2)
Waycross-Dry (WCD)	Lower Coastal Plain	Ware	Bonifay/Pacolet	C,H,F,HF	1987(2), 1989 (2),1993 (2)
Waycross-Wet (WCW)	Lower Coastal Plain	Ware	Pelham	C,H,F,HF	1987 (2), 1989 (2),1993 (2)

C = control; H = competition control; F = fertilizer only; HF = combination treatment of competition control and fertilization.

Table 2—Treatment information for Consortium for Accelerated Pine Production Studies study sites

Treatment	Regime
Control (C)	No added treatments other than initial site prep (bedding on Coastal Plain sites, shear, rake, pile, and disc on Piedmont sites)
Fertilization (F)	Spring application of 280 kg ha^{-1} DAP, 112 kg ha^{-1} KCl; a summer application of 56 kg ha^{-1} NH_4NO_3 for the first two growing seasons, followed by early to mid-spring application of 150 kg ha^{-1} NH_4NO_3 in growing seasons 3–9. Age 10 treatment was 336 kg $ha^{-1}$of NH_4NO_3 and 140 kg ha^{-1} triple super phosphate. Age 11 treatments included 560 kg ha^{-1} super rainbow with added micronutrients, and 168 kg ha^{-1} of NH_4NO_3 in early spring. Growing seasons 12 and on received 336 kg ha^{-1} of NH_4NO_3 in the early spring.
Competition control (H)	Repeated herbicide application to control herbaceous and woody plants
Fertilization + competition control (HF)	Combination of fertilization and competition control treatments

for the first 20 growing seasons. Biennial measurements began in growing season 21. Tree-level measurements include diameter at breast height, total height, and age. Initial planting density allotted 80 trees in the interior measurement plot.

Analysis

Measurement data was summarized at the plot, then treatment level for each site. Volume estimates were made utilizing the PMRC 1996 loblolly yield model for the appropriate physiographic region. Annual growth estimates were calculated from the difference in volume between observation years. Treatment response was calculated using the competition control treatment as a positive control. This method allows for the isolation of loblolly pine growth from competition and enables the comparison with other treatments' responses. To calculate response, volume for the competition control treatment was subtracted from the treatment of interest's volume.

RESULTS AND DISCUSSION

There was not a consistency in the response type curves for treatments across sites and physiographic regions. Sites in the Piedmont showed higher initial growth rates up to approximately age 10 for plots receiving competition control (fig. 1). Coastal Plain sites exhibited higher initial growth rates for plots receiving fertilization treatments for the first 10 to 15 years. Across all sites, the HF treatment showed higher initial growth

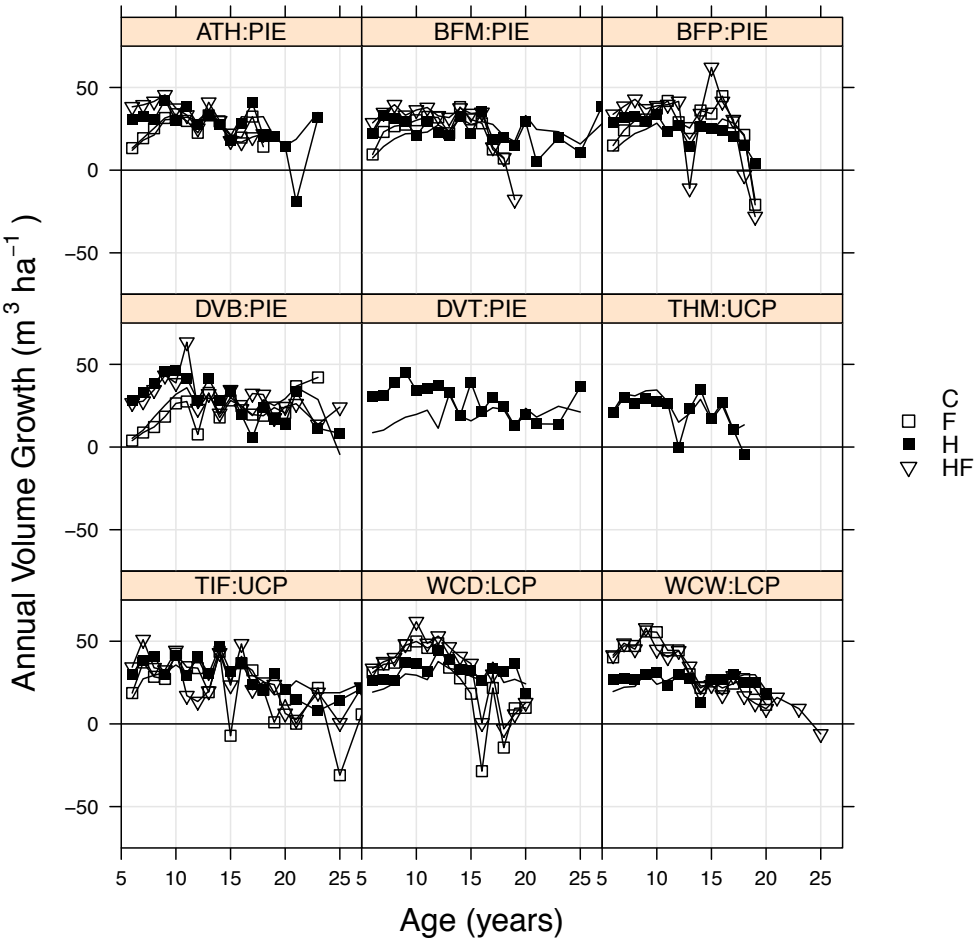

Figure 1—Annual volume growth (m^3 ha^{-1}) by site and physiographic region of the Consortium for Accelerated Pine Production Studies. ATH: Athens; BFM: Eatonton-Monitor; BFP: Eatonton-Powerline; DVB: Dawsonville-Bottom; DVT: Dawsonville-Top; THM: Thomson; TIF: Tifton; WCD: Waycross-Dry; WCW: Waycross-Wet; PIE: Piedmont; UCP: Upper Coastal Plain; LCP: Lower Coastal Plain.Coastal Plain.years after fertilizer application to the soil. The hatched bars highlight the control treatment at each site.

rates. Volume yield indicated a sustained increase in productivity in the long run. Shifts in volume growth after year 15 are the consequence of trees reaching full competition stage with mortality appearing in all plots with higher volumetric growth rates.

Treatment Response

When compared to the competition control treatment, sites receiving the interaction treatment exhibited different response types within and between physiographic regions (fig. 2). Piedmont sites showed initial positive response for treatment plots receiving the interaction treatment followed by a subsequent decline. Lower Coastal Plain sites showed initial positive responses to treatments containing fertilizer, also followed by a subsequent decline. Sites in Eatonton showed positive responses to the HF treatment. Dawsonville-Bottom showed Type D and no responses in the comparison of C, F, and HF to the H treatments. Negative responses (Type D) were observed in Piedmont sites, including the F treatment in Athens, and C in Athens and Dawsonville (both sites). The Waycross Wet site showed no difference in volume yield response between the competition control (H) and control (C) treatments, but decreases in volume yield response after age 15 can most likely be attributed to tree mortality (fig. 3). This is most likely a result of lack of competition on the site.

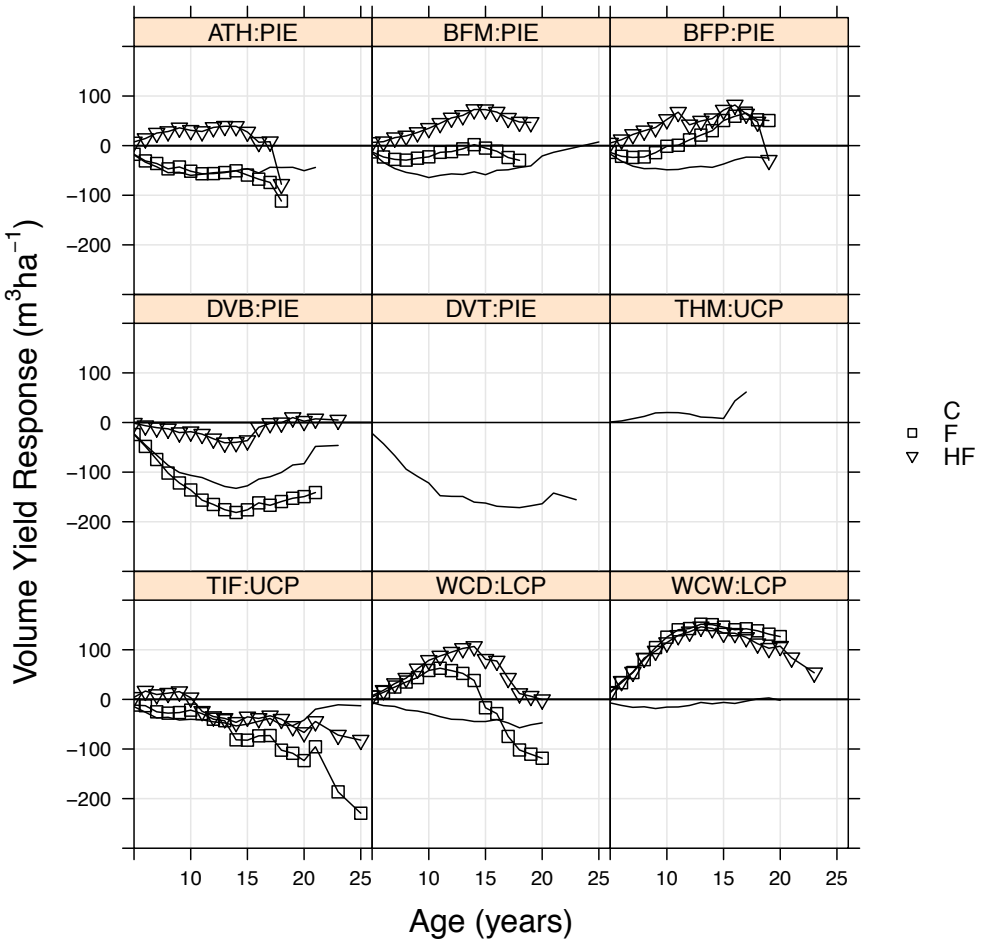

Figure 2—Volume yield response (m^3 ha^{-1}) for treatments by site as compared to the competition control treatment. ATH: Athens; BFM: Eatonton-Monitor; BFP: Eatonton-Powerline; DVB: Dawsonville-Bottom; DVT: Dawsonville-Top; THM: Thomson; TIF: Tifton; WCD: Waycross-Dry; WCW: Waycross-Wet; PIE: Piedmont; UCP: Upper Coastal Plain; LCP: Lower Coastal Plain.

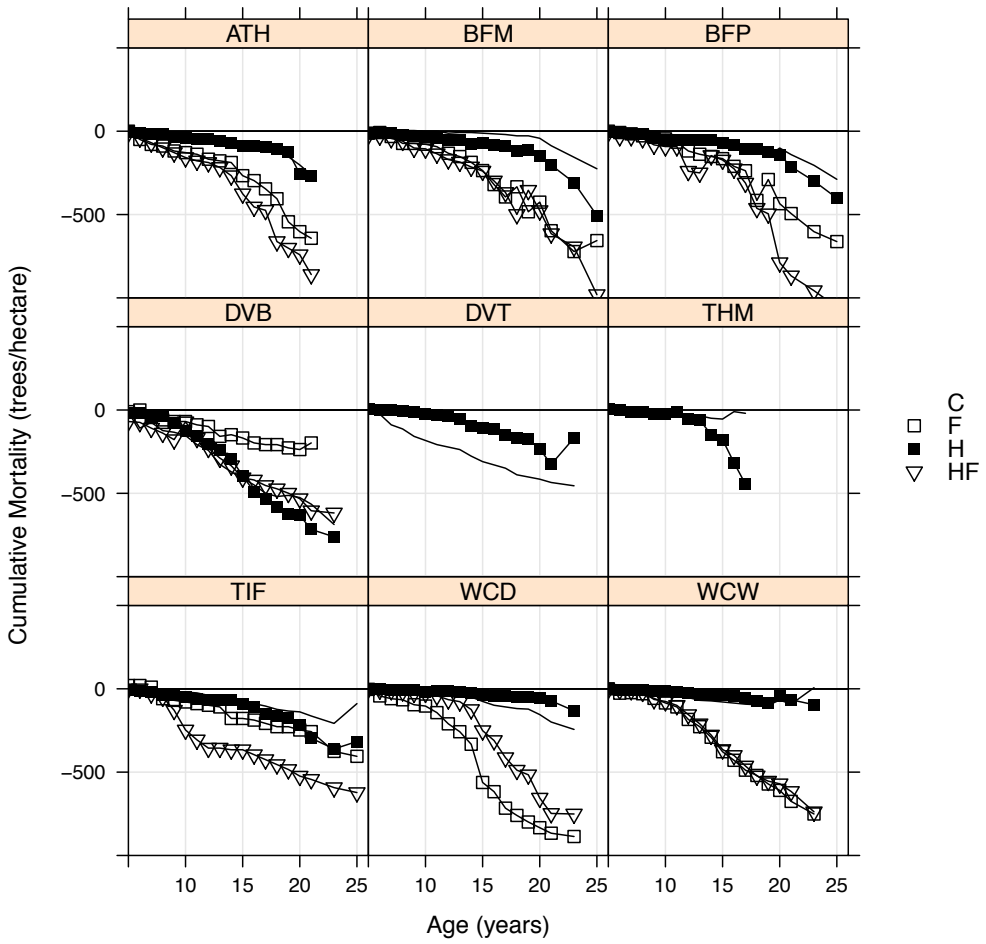

Figure 3—Cumulative mortality (trees ha^{-1}) by site of the Consortium for Accelerated Pine Production Studies. ATH: Athens; BFM: Eatonton-Monitor; BFP: Eatonton-Powerline; DVB: Dawsonville-Bottom; DVT: Dawsonville-Top; THM: Thomson; TIF: Tifton; WCD: Waycross-Dry; WCW: Waycross-Wet.

CONCLUSION

While treatments applied in this study are not operational and intensities will not be seen at scale, results indicate that response trends are not consistent. Knowledge on inherent site properties, such as nutrition levels and competition type and amount, is necessary to select treatments that will result in the best response and not waste resources on ineffective treatments. For sites that showed a relatively slight difference between treatments, such as HF and F on the Waycross-Wet site, we can assume that there was little to no direct competition to be controlled, due to no added response from the competition control component in the HF treatment. With increased growth rates following treatment application, we hypothesize that site carrying capacity must have been increased.

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