RESPONSE OF 1- TO 4-YEAR-OLD UPLAND HARDWOOD STANDS TO STOCKING AND SITE MANIPULATIONS

Jamie L. Schuler and Daniel J. Robison[1]

Abstract—The growth and development of very young natural even-aged hardwood stands is not well understood. The relative importance of biotic and abiotic constraints such as overstocking, herbaceous competition, tree nutrition, and pest impacts have not been widely studied in these types of stands. Earlier work has demonstrated significant tree growth response (2- to 20-fold) to release from these constraints. This paper will report on the continued measurement of these plots through year 4. Also, a new series of plots in 1 and 3 year old stands have been followed for 1.5 years. Treatments imposed include thinning, herbaceous competition control, fertilization, and combinations of these treatments. These experiments are beginning to show the potential of very early stand interventions to shorten rotation ages in upland hardwoods. These efforts are part of a broader set of initiatives across the South by the NC State Hardwood Research Cooperative to explore early interventions for stocking and competition control as a silvicultural option in managing hardwoods.

INTRODUCTION

The growth and development of very young natural even-aged hardwood stands is not well understood. While a general understanding of regeneration and self-thinning processes is accepted, the relative importance of biological constraints such as tree stocking, herbaceous competition, tree nutrition, and pest impacts have not been widely studied in these types of stands. Earlier work has demonstrated significant tree growth response (2- to 20-fold) to release from these constraints at ages 1 and 2 (Romagosa 1999, Romagosa and Robison 1999).

Southern hardwoods are often managed under an even-aged silvicultural system, with clearcutting prescribed as the regeneration method. Clearcutting commonly regenerates 25,000 - 100,000 stems/hectare. Given that current rotations for pulpwood and sawtimber at completion contain about 1000 and 250 harvestable stems/hectare, respectively, it seems apparent that 25,000 or more stems/hectare at establishment is well overstocked. This overstocking is often cited as a major factor constraining growth in forest stands. The numerous seedlings and sprouts from undesirable species retard the growth of more desirable species (Kays and others 1988).

A large number of thinning studies in young stands between 9 and 20 years of age were published, most with beneficial results (e.g. Heitzman and Nyland 1991, Johnson and others 1997, Pham 1985, Smith and Lamson 1983). However, the degree to which density affects growth at younger ages has not been quantified. Similarly, weed competition (herbaceous and woody) is known to seriously impede growth. This has been documented in plantations and natural stands for hardwood and coniferous species (e.g. Kolb and others 1989, Miller and others 1995, Nelson 1985, Romagosa and Robison 1999), but not evaluated fully within the control of other constraints.

Other biotic factors known to depress growth and prolong rotations include deer browse, and insect and fungal attack (Galford and others 1991, Korstian 1927, Marquis 1981). Experiments with deer exclosures through fencing and chemical repellants have demonstrated dramatic differences in height growth and species composition (Brenneman 1983, Marquis 1981). Stanosz (1994) used systemic pesticides to control insects and fungi on 1-year-old sugar maple (*Acer saccharum*) seedlings and had positive effects.

Tree nutrition has received much research attention, demonstrating the exceptional gains in productivity possible with fertilization (Allen and others 1990). Little nutrition research has focused on young hardwood stands outside of plantation culture. The few published studies show mixed results. Graney and Rogerson (1985), working with shelterwood regeneration, reported no effect of nitrogen fertilization on 5-year heights for oak seedlings, but increased white ash (*Fraxinus americana*) and cherry (*Prunus serotina*) 5-year heights. They cited extreme herbaceous competition exacerbated by fertilization as the cause. By contrast, significant responses to nitrogen and phosphorus were shown for 7 and 12 year old black cherry (*Prunus serotina*) stands in Pennsylvania (Auchmoody 1985) and 7 year old mixed hardwoods in North Carolina (Newton and others, this issue).

In the current study we report on the results of 2 studies. Both focused on factors constraining tree growth in very young (1 to 4 years old) naturally regenerated hardwood stands. In Experiment One, we report the 4-year effects of ameliorating weed competition and pest impacts for 2 years. In Experiment Two, we quantified the effects of overstocking, weed competition, and fertilization on very young upland hardwood stands.

[1]Graduate Research Assistant and Assistant Professor & Director of Hardwood Research Cooperative, Department of Forestry, North Carolina State University, 3118 Jordan Hall, Raleigh, NC 27695, respectively.

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METHODS

Experiment One

Experiment One was installed on three clearcut sites in the North Carolina Piedmont. The sites are located on 2 of the NC State University owned forests, the Schenck Memorial Forest (Wake County) and the Hill Forest (Durham County). Each site was salvage clearcut during the winter of 1996/97, prompted by hurricane Fran. The three sites have previously held stands of mixed pine-hardwoods, natural mixed hardwoods, and loblolly pine plantation. All sites have south-facing aspects and Cecil sandy loam soils on 2-10 percent slopes.

Four treatments were applied to 10 square meter square plots with 1 meter borders in a randomized complete block design with 4 replications. The treatments, applied during the growing seasons of 1997 and 1998 (years 1 and 2 after clearcutting), consisted of:

(1) Pesticide- an insecticide, fungicide, and mammal repellant sprayed periodically over the vegetation
(2) Weeded-hand shearing of all non-hardwood vegetation
(3) Full- pesticide and weeded treatments
(4) Untreated control

Due to space restrictions, site 1 had all four treatment plots, site 2 only treatments 3 and 4, and site 3 had treatments 1, 3, and 4. More detailed site and experimental design descriptions are contained in Romagosa and Robison (1999). The data reported include the 2 years when treatments were applied (age 1-2) and the 2 years after treatments were discontinued (age 3-4).

Experiment Two

Treatments were established on 2 upland North Carolina Piedmont sites. The Hill site (Hill Forest, Durham County), formerly a 2 hectare loblolly pine (*Pinus taeda*) stand with a small component of hardwoods, was clearcut logged in 1999. The Duke site (Duke Forest, Orange County), formerly a 5 hectare mature mixed oak (*Quercus sp.*) stand, was salvage clearcut in 1996/97 in response to damage from hurricane Fran. The Hill site has Cecil soils with undulating topography. The Duke site has Appling silt loam soils with a north-facing aspect on 2-10 percent slopes.

Ten square meter circular plots with 1 meter borders were randomly located, insofar as each plot contained at least 2 yellow-poplar (*Liriodendron tulipifera*) and 2 oak trees. Each site contained a total of 8 treatments replicated in 4 blocks. The treatments were begun in July 1999 and continue to the present. The treatments were installed in a 2x2x2 factorial design with the main factors being:

(1) Weeded vs. unweeded- hand removal of all non-arborescent vegetation
(2) Fertilized vs. unfertilized- 90 kilograms/hectare of nitrogen and 100 kilograms/hectare of phosphorus applied as diammonium phosphate
(3) Thinned vs. unthinned-stem density reduced to 4 stems/plot, consisting of 2 yellow-poplar and 2 oak trees

The data reported for Experiment Two focus on the 5 most dominant yellow-poplar in each of the unthinned plots and the 2 yellow-poplars in each thinned plot. Therefore, the data represented a total of 8 stems on thinned and 20 on unthinned plots. This was done to reduce the error associated with different species composition among treatments and blocks. Yellow-poplar was selected for comparison because it represents an important timber species in the region, it existed in all plots, and as a fast-growing shade intolerant species it provides a rapid measure of treatment effects.

Table 1—Density and growth response for 3 (1997) and 4 (1998)-year-old hardwood and pine seedlings in Experiment One (see text for description) averaged across three upland North Carolina Piedmont sites. Pines had been removed from the weeded and full study plots during years 1 and 2

		Stem Count (No./10 m^2)		Basal Diameter (mm)		Total Height (cm)	
Treatment	Species	1999	2000	1999	2000	1999	2000
Control	hardwood	163	163	8.7	11.8	61	107
	Pine	146	193	13.2**	20.0**	78**	131**
Pesticide	hardwood	60	60	8.7	12.7	64	113
	pine	178	196	11.8**	19.7**	76*	137**
Weeded	hardwood	163	153	14.0	17.2	85	116
	pine	0	0	-	-	-	-
Full	hardwood	353	376	16.3	18.9	110	145**
	pine	0	7	-	1.4	-	14

Significant differences between hardwood and pine seedlings within each treatment/year pair are designated by * for alpha = 0.1 and ** for alpha = 0.05. Stem count data were not analyzed for differences. Pesticide treated plots received a combination of pesticides only, weeded plots had all non-hardwood vegetation removed, and the full treatment was pesticide + weeded. Treatments were applied during years 1 and 2, then discontinued.

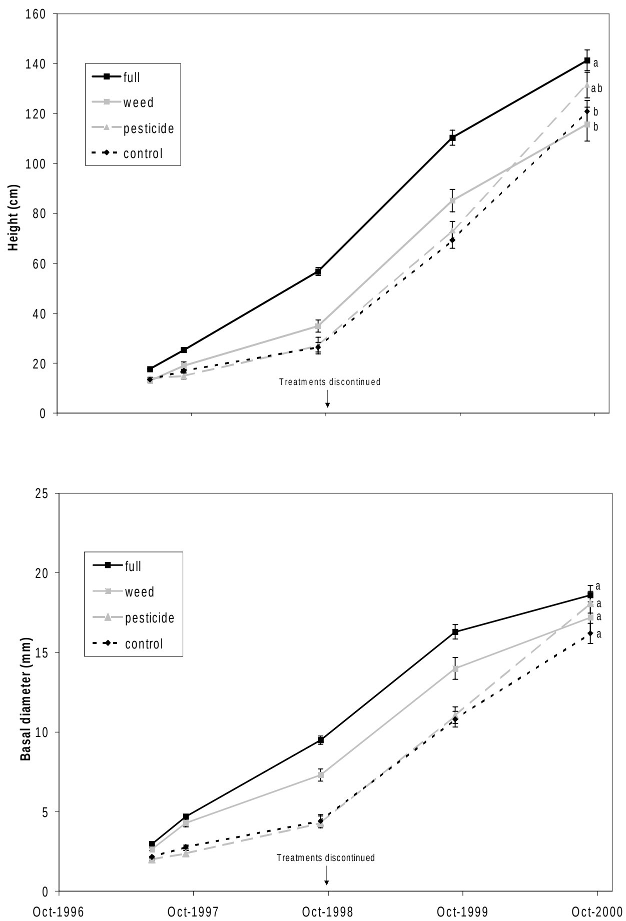

Figure 1—Mean height (top) and basal diameter (bottom) (3 sites, 8-12 plots per treatment) of natural regeneration following winter 1996/97 clearcutting on NC upland Piedmont sites. Different letters indicate statistical differences at alpha = 0.05 using ANOVA protected LSD means separation procedure. The arrow indicates the time when treatments were discounted.

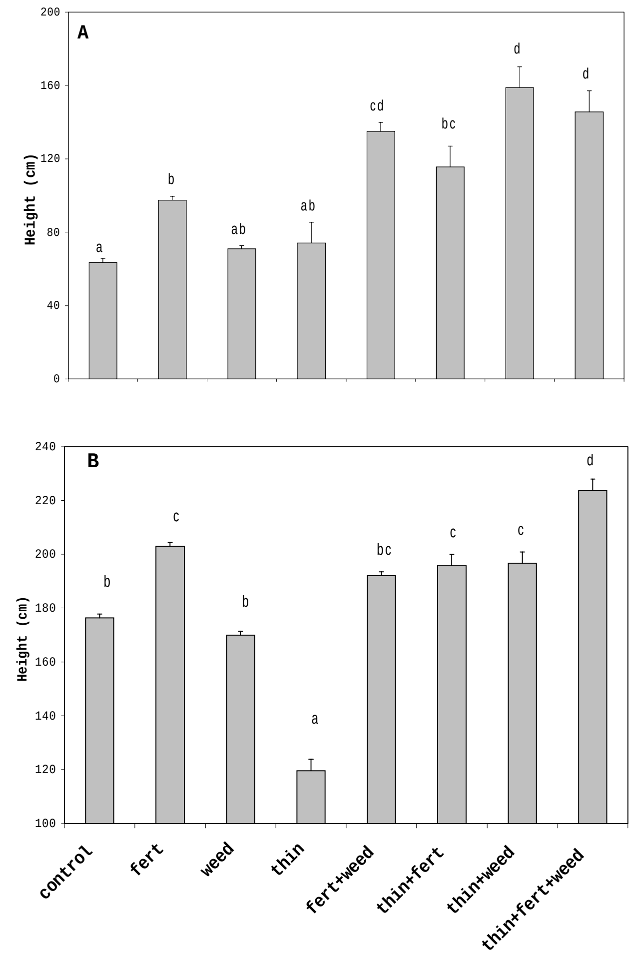

Figure 2—Mean (+/-SE) height of dominant yellow-poplar at age 2 (1.5 years of treatment) at the Hill Forest (a, top), and at age 4 (1.5 years of treatment) at the Duke forest (b, bottom). Different letters indicate statistical differences at alpha = 0.05 using ANOVA protected LSD means separation procedure.

RESULTS AND DISCUSSION

Experiment One

Romagosa and Robison (1999) reported substantial and significant gains attributed to weeding and full treatments for the first 2 years of treatment. After 4 years of growth (treatments were applied during the initial 2 years) the full treatment still has greater cumulative heights and diameters, but significant differences ($P < 0.05$) only occurred for height growth (figure 1). By year 4, the pesticide and control treatments marginally surpassed the weeded treatments in height and diameter growth. These trends suggest convergence among treatments.

However, the application of the treatments inadvertently complicated the study. For the weeded and full treatments, all non-hardwood vegetation, including pine trees, were periodically sheared for 2 years. As a result, we are seeing the effects of loblolly pine on the control and pesticide treated plots (where they were not removed) beginning to out compete the hardwood seedlings on these shallow Cecil soils with southerly-facing slopes. On the control and pesticide treated plots at the end of year 4, loblolly pine accounted for roughly 50 and 75 percent of the stem count, respectively. By the end of the 4th growing season (2000), the loblolly pine component was accumulating more diameter and height growth than the hardwoods (table 1). By examining the curves in figure 1, and either mentally factoring pines into the full and weeded plots, or factoring them out of the pesticide and control plots, the trends do suggest a continuing positive effect of the treatments.

Experiment Two

Initial height measurements were significantly different ($P<0.05$) among treatments for both sites. Therefore, the 2000 cumulative height data were adjusted using initial height as a covariate.

Fertilization significantly improved yellow-poplar height growth (+ 54 percent) after 1.5 years on the 2-year-old Hill site (figure 2a). The combination of fertilization + weeding showed a positive interaction ($P = 0.0791$), as did thinning

+ weeding (P = 0.0587). Results suggest that weeds compete more strongly than seedlings with the dominant yellow-poplar trees. However, when both competitors were removed large gains in height growth were observed.

Fertilization significantly enhanced yellow-poplar height growth (+15 percent) after 1.5 years, on the 4-year-old Duke site (figure 2b). Again, weeding and thinning treatments had no measurable positive effect on dominant yellow-poplar height growth. Fertilization out performed all other treatments except for the combined effects of thinning + fertilization + weeding. We surmise that the availability of nutrients became limiting on this site as tree seedlings and other vegetation competed for the similar resources. Even when thinning, weeding, and fertilization treatments are combined, the yellow-poplar trees only grew 10 percent more than for fertilization alone.

CONCLUSIONS

The objectives of this work were to determine if early stand interventions could be used to identify factors that constrain productivity on upland Piedmont sites. Both experiments demonstrate the potential of early silvicultural treatments to accelerate growth and possibly reduce rotation lengths.

The 4-year results (through age 4) from Experiment One suggest that early gains are sustainable even after treatments are discontinued. Full treatments have maintained a growth advantage over all other treatments.

In Experiment Two, both the 1- and 3-year-old stands responded well to fertilization after 1.5 years. Thinning and weeding treatments suggest that at very early ages weed competition is more severe than competition from other seedlings, at least for dominant yellow-poplar seedlings. Thinning and weeding showed synergistic effects when combined together.

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