THE RESPONSE OF TWO VERY YOUNG NATURALLY REGENERATED UPLAND HARDWOOD STANDS TO WEED CONTROL AND FERTILIZATION

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Abstract—Two newly regenerated hardwood forest stands in the Piedmont of North Carolina were examined to determine the potential to accelerate productivity in young stands. Factorial combinations of fertilization and vegetation control treatments were applied to 1-year-old and 3-year-old stands. After three growing seasons, fertilization improved growth rates at both sites. The collective species response to NPK fertilization was a doubling of individual seedling volume. Weeding failed to significantly increase growth over nonweeded seedlings, and the combined weeding and fertilization effects were additive (no interaction). Stem densities declined markedly after 3 years. Mortality at the lower end of the initial height distribution was increased on the fertilize-only plots, suggesting that the substantial increase in height in the fertilization treatment was not completely attributable to enhanced growth rates alone. These results highlight that young stands may not be performing up to their potential, and that early stand intervention can be a viable management strategy.

INTRODUCTION

Southern upland hardwood forests, including the Piedmont region, are often characterized as having low productivity. Most of the Piedmont has suffered from severe soil erosion, and many hardwood stands have been repeatedly subjected to selective harvesting with few if any improvement cuttings. As a result, these stands have average growth rates of about 5 m^3/ha per year (Roeder and Gardner 1984). With increasing harvests predicted in the Piedmont region because of an expected increased market demand for hardwood roundwood and chips (Prestemon and Abt 2002), many thousands of hectares of newly regenerated stands are being created that will produce mixed species stands starting with 40,000 to 100,000 stems/ha (Schuler and others, in review). Another 3 or 4 decades will typically pass before the next treatment, usually a commercial thinning. By this time, one-third to one-half the rotation may have passed without any attempt to improve productivity or species composition, thereby increasing the likelihood of a continued cycle of sub-optimal productivity and, without timber stand improvement, a high-representation of low-value species.

In young natural hardwood stands, low productivity has been attributed to overstocking (Kellison and others 1981) and the delayed onset of crown closure due to intense competition from competing vegetation (Romagosa and Robison 2003). Managing stem density and competing vegetation has led to positive effects on individual tree growth in young stands (Johnson and others 1998, Pham 1985, Robison and others 2004).

Soil nutrient management has also received substantial attention in the Southern United States. Over 500,000 ha of pine plantations are fertilized annually (NCSFNC 2002). Studies have also shown that fertilization, especially with nitrogen (N) and phosphorus (P), can be very beneficial for hardwood stands by increasing growth rates and accelerating self-thinning (Auchmoody 1985, Haines and Sanderford 1976, Newton and others 2002, Schuler and Robison 2002). Recent economic modeling activities indicate investments upwards of U.S. $320/ha in year 1 in natural hardwoods are potentially profitable investments if productivity can rise from 4.7 to 6.9 tons/ha per year due to management activities (assuming IRR=7.3 percent) (Siry and others 2004). These projections indicate that investments such as broadcast weed control and fertilization (Dubios and others 2003) made soon after regeneration treatments (e.g., year 1 to 3) are financially feasible.

The objective of this study was to assess how fertility and competing vegetation affect growth and development of very young mixed species Piedmont stands of naturally-regenerated hardwoods. By manipulating factors that potentially constrain resource availability, opportunities to increase productivity in upland Piedmont stands may be realized.

METHODS

Two upland sites in the North Carolina Piedmont were studied. One site was on the North Carolina State University Hill Demonstration Forest (Hill), located in Durham Co., NC, and was formerly a natural 2-ha loblolly and Virginia pine (*Pinus taeda* L. and *P. virginiana* Mill., respectively) stand with a lesser component of mixed hardwoods. This site was regenerated through clean clearcutting in winter 1998-1999. Site two was on the Duke University Forest (Duke), located in Orange Co., NC, and was formerly a 5-ha mature natural mixed oak (*Quercus* spp.) stand. This site was regenerated following a salvage clean clearcut operation in the winter 1996-1997 following damage from Hurricane Fran (September 6, 1996). The two sites are approximately 24 km apart.

The Hill site has Georgeville silt loam soils with a mainly north-facing aspect on slopes of < 5 percent (Kirby 1976). The Duke site has Wedowee sandy loam soils with a north-facing aspect on a 2 to 10 percent slope (Personal communication, 2004, Judson Edeburn, Duke Forest Manager, Office of the Duke Forest, Box 90332, Duke University, Durham, NC 27708).

Sixteen 10-m^2 circular plots with an additional 1-m treated border were located on each site with the criteria that each plot contained at least two yellow-poplar (*Liriodendron tulipifera* L.) and two oak stems (putatively seed or seedling-sprout

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origin), no obvious large stump sprouts, and were not in heavy slash concentrations or on skid trails. For each site, four treatments were replicated in four blocks based on topography. The treatments began in June, 1999, and continued through the end of the 2001 growing season. The study was installed as a 2x2 factorial design with or without the following main factors:

1. Weeding- repeated hand removal of the aboveground portion of all non-arborescent vegetation in years 1 to 3.
2. Fertilization- in June, 1999, with 90 kg N/ha and 100 kg P/ha applied as diammonium phosphate, and in March, 2001, with 100 kg N/ha as urea and 100 kg K/ha as muriate of potash.

Stem heights (±1 cm) and basal diameters (±0.1 mm) were recorded for all arborescent species in spring, 1999, prior to the installation of treatments on all plots. Stem heights and diameters were again measured on all plots at the end of the 2001 growing season and 3 years after treatments were imposed. Stem volumes were calculated as conical volume. Each stem at the Hill Forest site was permanently marked with an aluminum tag embossed with a unique identification number prior to the initiation of treatments. Additional stems that emerged over the duration of the study were tagged at each measurement cycle. The presence and survival of individual stems was used to assess patterns of recruitment and mortality.

Stem densities and stem height, diameter, and volume were analyzed using analysis of variance (ANOVA) (SAS 1990) with the respective initial measurement parameter as a covariate. Therefore, reported means are based on least-squares estimators. Main effects and interactions were evaluated for significance at P<0.1. Logarithmic transformations were applied to volume data to correct for heteroscadasticity.

RESULTS

Hill Forest

Pretreatment stem densities on these plots averaged 169,750 stems ha^{-1} with over 20 species represented. No statistical differences were detected in initial stem densities. Species composition was dominated on all plots by yellow-poplar (64 percent of all stems), dogwood (*Cornus florida* L., 5.9 percent), sumac (*Rhus* spp., 5.2 percent), red maple (*Acer rubrum* L., 4.1 percent), river birch (*Betula nigra* L., 3.9 percent) and black cherry (*Prunus serotina* Ehrh., 3.1 percent).

Although species composition varied little throughout the 3-year study, stem densities changed markedly (table 1), mostly as a result of stem mortality. Stem density on control plots increased 21,000 stems ha^{-1} by the end of the third growing season (3GS). Weeded-only and weeding+fertilization treatment plots had an 18 to 21 percent reduction in initial stem density following year 3. By contrast, stem numbers declined dramatically (>50 percent) by the end of the 3GS on the fertilized-only plots. Stem density was affected by a weeding and fertilization interaction following the 3GS (P=0.049). Stem density after 3 years on fertilize-only plots was significantly less than the control and weeded plots.

The recruitment of new individuals ranged from 18 to 38 stems per plot over 3 years. Fertilized plots had reduced recruitment, although differences were not statistically significant (table 2).

Table 1—The effect of weeding and fertilization treatments on stem density on a rising 1-year-old (Hill Forest) and on a rising 3-year-old (Duke Forest) naturally-regenerated upland NC Piedmont stand

Site		Control	Fertilized	Weeded	Weeded + fertilized
		stems/10 m^2			
Hill	age 0[a]	130	206	184	159
Forest	age 3	151	87	151	125
Duke	age 3[b]	79	104	90	87
Forest	age 5	107	94	123	95

[a] At the Hill Forest, age 0 is the pretreatment stem density of a rising 1-year-old stand.
[b] At the Duke Forest, age 3 is the pretreatment stem density of a rising 3-year-old stand.

Net stem mortality (total mortality minus total recruitment) among treatments was 25, 47, 29, and 34 percent of the initial stem density after the 3GS for the control, fertilized, weeded, and weeded+fertilized treatments, respectively. Total mortality among stems present pretreatment was affected by a weeding and fertilization interaction (P=0.086). Three-year mortality averaged 37, 114, 67, and 59 stems per plot on the control, fertilized, weeded, and weeded+fertilized treatment plots, respectively.

Stem mortality among all treatments was generally restricted to the small size classes. The average median initial height for stems that died was 19, 21, 20, and 26 cm for the control, fertilized, weeded, and weeded+fertilized treatments, respectively, and did not differ significantly among treatments. The mean initial height for stems that died was 20, 24, 23, and 30 cm for the control, fertilized, weeded, and weeded+fertilized treatments, respectively. With mortality separated into 20-cm height classes, fertilization increased stem mortality in the 0 to 20 and 21 to 40 cm height classes (fig. 1), but variation was to too great to detect statistical differences. Significant treatment differences were found in stem mortality in the 81 to 100 and 101 to 120 cm height classes, but differences amounted to less than 4 stems per plot over the 3-year period.

No significant pretreatment differences were detected for height, diameter, or volume on plots delineated to become control, fertilized, weeded, or weeded+fertilized plots (table 3). Stem height on fertilized plots increased 22 percent, while diameter increased 29 percent over non-fertilized stems. Weeding was effective in increasing stem diameter in both growing seasons following the initial treatment applications but did not significantly affect stem height or volume. Compared to non-weeded plots, the diameter of weeded stems was 29 percent greater.

Duke Forest

Pretreatment stem densities averaged 90,000 stems ha^{-1}, with over 20 species recorded. No pretreatment statistical differences existed among plots. Pretreatment species composition was dominated by yellow-poplar (59.4 percent of all stems), white oak (*Quercus alba* L., 20.8 percent), red oak (*Q. rubra* L., 5.7 percent), dogwood (5.9 percent), red maple (2.6 percent), and hickory (*Carya* spp., 2.6 percent).

Table 2— The number and distribution of newly-recruited stems by height class (cm) and growing season for the Hill forest site on 10 m² plots

	End of 2nd growing season (2-year-old stems) treatments				End of 3rd growing season (3-year-old stems) treatments			
Height class	Control	Fertilized	Weeded	Weed+fert	Control	Fertilized	Weeded	Weed+fert
1 - 20	15.0	4.0	16.0	5.5	0.3	0.0	1.3	0.0
21 - 40	3.3	5.0	8.3	2.0	2.0	0.5	3.0	0.8
41 - 60	3.0	3.5	2.5	1.8	5.0	0.0	1.5	1.0
61 – 80[a]	2.5	3.0	1.3	0.5	2.3	1.3	0.5	0.3
81 - 100	1.0	1.3	1.0	0.5	1.0	0.8	0.3	0.3
101 - 120	0.3	1.0	0.8	0.5	1.0	0.3	0.0	1.0
121 - 140	0.3	0.5	0.0	0.5	0.3	0.3	0.0	1.0
141 – 160[a]	0.0	0.3	0.0	0.3	0.0	0.0	0.3	0.5
161 - 180	0.0	0.0	0.0	0.5	0.3	0.3	0.5	0.3
180 - 200	0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.3
201 - 220	0.0	0.5	0.0	0.5	0.0	0.5	0.3	0.0
All	25.3	19.0	29.8	12.8	12.3	4.0	7.5	5.3

[a] Significance at $P \leq 0.10$ was detected for height class 61-80 for the main effect of weeding, and for height class 141-160 for the main effect of fertilization.

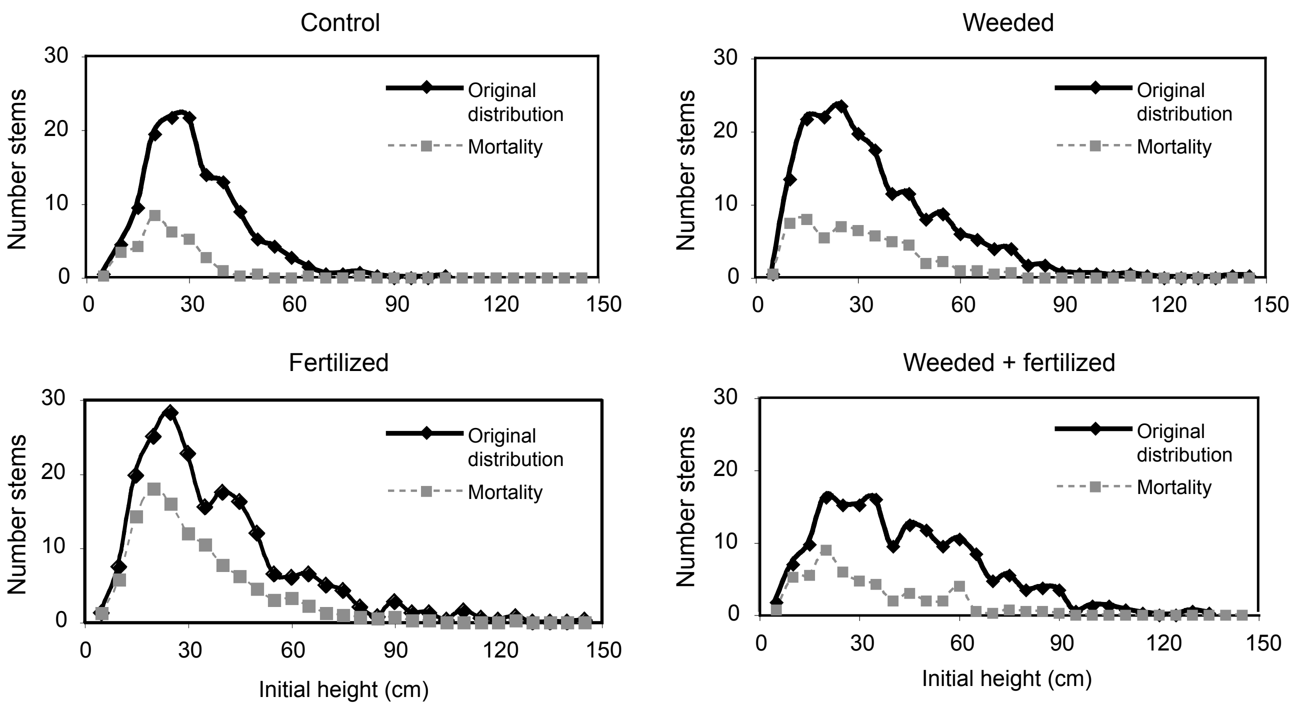

Figure 1—The initial distribution of rising 1-year-old stems (solid black line, by 5-cm height classes) and cumulative mortality (grey dashed lines) after three growing seasons for the Hill Forest site.

Individual stems were not tagged at this site, making it impossible to determine specific recruitment and mortality patterns. Nonetheless, plot inventories revealed stem density patterns associated with the treatments (table 1). Fertilized plots had reduced stem density, and weeded plots had increased stem density 3 years after treatment, although not always significantly. The weed x fertilization interaction was not significant.

Fertilization significantly increased stem growth (table 3). Responses to fertilization for height, diameter, and volume averaged 35, 19, and 86 percent over non-fertilized stems, which averaged 155 cm, 18 mm, and 21 cm³ for height, diameter, and volume, respectively.

DISCUSSION

Many natural hardwood stands have been reported to be responsive to a variety of early stand interventions. Site modification treatments have generally focused on improving nutrient availability through fertilization, largely with N and P, and have been beneficial for many species and sites (Auchmoody 1972, Beckjord and others 1983, Demchik and Sharpe 1999, Kolb and others 1990, Newton and others 2002). Vegetation control treatments that remove competing herbaceous and undesirable woody species and/or overtopping residuals have also been beneficial in certain circumstances (Leak 1988, Petruncio and Lea 1985, Romagosa and Robison 2002,

Table 3—The effect of weeding and fertilization treatments on a rising 1-year-old (Hill Forest) and on a rising 3-year-old (Duke Forest) naturally-regenerated upland NC Piedmont stand for all species combined[a]

		Height		Diameter		Volume	
Hill Forest	Treatment	Age 0	Age 3	Age 0	Age 3	Age 0	Age 3
		- - - - - *cm* - - - - -		- - - - *mm* - - - -		- - - *cm³/stem* - - -	
	Control	29.7	103.2	4.6	10.3	1	14
	Fertilized	32	137.7	4.5	13.5	1	36
	Weeded	31.4	119.2	4.2	12.4	1	28
	Weed + Fert	37.2	133.5	4.6	15.7	1	42
Main Effects	Fertilization	—	0.023	—	0.035	—	—
(P-value)	Weeding	—	—	—	0.015	—	—
Duke Forest	Treatment	Age 3	Age 5	Age 3	Age 5	Age 3	Age 5
	Control	77.2	155.5	10.1	17.6	14	65
	Fertilized	63.5	212.4	8.9	20.8	8	141
	Weeded	63.2	154.2	8.7	19.2	8	76
	Weed + Fert	70.9	205.4	9.3	22.9	12	153
Main Effects	Fertilization	—	<0.001	—	0.025	—	<0.001
(P-value)	Weeding	—	—	—	—	—	—

[a] All volumes were analyzed using $\log_e$ transformed data. The reported least-square means were back-calculated for ease of interruption.

Young and others 1993). Results from this study demonstrate that in North Carolina Piedmont hardwoods, fertilization was very successful in increasing growth and accelerating early stand development (see table 3).

Broadcast fertilization generally produced a large and sustained increase in height, diameter, and volume in the current study. The collective species response to nutrient additions was a 2- to 3-fold increase in individual stem volume. This type of response to fertilization can be expected on many Piedmont sites, which have experienced severe soil erosion over the last century (Daniels and others 1999). Many of the soils are left with only a thin surface horizon overlaying a thicker Bt horizon and consequently are generally low in organic matter, N, and other nutrients (Della-Bianca and Wells 1967).

Concurrent with increased growth, stem densities were reduced on fertilized plots even in the short time span of this study. This suggests other essential growth resources very quickly become limiting (e.g., water and/or light) among tree stems, or that non-arborescent vegetation out-competes trees for these other resources. The data also suggest that the large response to fertilization was due, in part, to mortality at the lower end of the initial height distribution, indicating the expected relationship between competition, growth, and density reductions. For the fertilization-only treatment, a larger proportion of mortality occurred in the smaller height classes (0 to 20 cm) compared to the other treatments (fig. 1). The establishment of new stems, either from seed or sprouts, also appears retarded under fertilization treatments, although the variation among treatments was large. Therefore, the large increase in stem size in the fertilization-only treatments may not be completely attributable to fertilization but rather to enhanced mortality and reduced recruitment of smaller stems, thereby providing more site resources to fewer stems.

Weeding treatments increase the availability of light, water, and nutrients, and allocate these resources that would otherwise be utilized by competing vegetation to tree stems. The benefits of weeding hardwood plantations have been well documented (e.g., Fitzgerald and others 1975, Nelson 1985, Schuler and others 2004). However, few studies have reported the effects of competing vegetation on young naturally-regenerated hardwood stands (McGill and Brenneman 2002, Romagosa and Robison 2003). In the current study, weeding had a limited effect on stem growth, with a few noted exceptions. It was visually apparent, but not quantified, that the weed biomass at the Hill Forest site was greater and therefore more competitive than at the Duke Forest site, due to the younger age of the Hill stand. The stem height and volume response to weeding treatments reported for this study differed from those of Romagosa and Robison (2003). They reported significant growth responses to weeding-alone on similar sites but with lower initial densities and large shifts in species dominance (Schuler and Robison 2002). No large shift in species composition at the Hill or Duke Forest sites was noted through the 3 years of this study. The effect of weeding treatments is also subject to variation in annual precipitation (wet versus dry years), with the impact of vegetation control generally more pronounced on dry sites and in dry years (Powers and Reynolds 1999). The monthly precipitation patterns for the Hill and Duke Forest sites were normal or slightly above normal during the 2000 and 2001 growing seasons. The 1999 growing season had a 10-cm precipitation deficit in May (based on long-term average) that could have affected growth and survival, especially for small, newly-germinated seedlings with underdeveloped root systems.

CONCLUSIONS

This study demonstrates that even the youngest naturally-regenerated upland forest stands in the North Carolina Piedmont are not achieving their maximum individual tree growth potential. On these Piedmont sites, young stands are overstocked and growing on soils deficient in soil nutrients. Reducing competing herbaceous vegetation produced a marginal response for yellow-poplar and oaks. Broadcast fertilization greatly accelerated growth and provided an added benefit of reducing stem density. Although further work on larger study plots will be required to determine whether these responses can be maintained in the future on these upland sites, there do appear to be opportunities to manage regeneration in newly-established stands.

Future work will be needed to assess whether fertilization and vegetation control treatments can modify species composition in a way that favors more desirable species. The use of species-specific fertilizer mixes and rates may be useful if we can show preferential uptake and use among hardwood tree species. Similarly, with target specific herbicides, more species selection opportunities may be available for mixed hardwood stands.

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