GROWTH RESULTS FROM 20-YEAR-OLD LOW DENSITY PINE PLANTATIONS

A. Gordon Holley and Charles T. Stiff[1]

Abstract—In 1994, under a cooperative effort between Temple-Inland Forest Products Corporation and Stephen F. Austin State University, 84 permanent research plots were established in two loblolly pine (*Pinus taeda*) plantations in eastern Texas. The study was designed to evaluate the effects of heavy thinning, pruning, fertilization, and competition control on future growth and yield. Three different levels of thinning treatments on randomly selected plots reduced basal areas to 36, 60, and 84 square feet (approximately 100, 200, and 300 stems, respectively) per acre. All residual trees were pruned to a height of 25 feet. Treatments also included two levels of fertilization (fertilized and not fertilized) and two levels of competition control (herbicide and no herbicide). The objective of this paper is to summarize the growth responses on these research plots 8 years after application of cultural treatments.

INTRODUCTION

Intensive management of loblolly pine (*Pinus taeda*) plantations, also known as sudden sawlog management, has gained much attention since the initial reporting by Burton (1982). Over the past two decades, several studies have reported large gains in growth following aggressive fertilization and control of competing vegetation (Borders and Bailey 2002, Miller and others 1991, Pienaar and Shiver 1993). Multiple studies have found increased diameter growth following heavy thinning as well (Holley and others 1999, Wiley and Zeide 1992, Zahner and Whitmore 1960).

In 1994, Temple-Inland Forest Products Corporation (TIFPC), in cooperation with Stephen F. Austin State University, established 84 monumented experimental plots in two typical loblolly pine plantations in eastern Texas. This project, based on studies reported by Burton (1982) and Wiley and Zeide (1992), was designed to evaluate the effects of heavy thinning, pruning, fertilization, and competition control on sawlog production. The overriding goal was to economically produce large clear sawtimber on short rotations. The objective of this paper is to report growth results 8 years after application of cultural treatments.

METHODS

Data for this project come from long-term growth research plots located across two stands in eastern Texas, near the western edge of the southern pine forests. The two study sites differ in relation to soil drainage type. Site 1 is located in the southern corner of Angelina County and is considered a moderately drained site with a Moswell complex (Dolezel 1988). Site 2 is located in southeastern Anderson County and is considered a well-drained site with a Fuquay series (Coffee 1975). Both study areas were on nonold-field sites that were previously forested with loblolly pine and were planted with a local variety seed source. Sites 1 and 2 were planted in 1981 and 1982, with 1,080 and 611 trees per acre surviving in 1988 and 1993, respectively. At the time of plot establishment, the understory at site 1 was almost nonexistent, whereas site 2 contained a heavy mix of woody shrubs and hardwood saplings.

The study was implemented during the summer of 1994, while the stands were in their 14th and 13th growing season, respectively. Plots were positioned within the two stands in a strip-wise pattern as close together as possible while maintaining uniformity and avoidance of windrows, skid roads, drainages, trails, and other anomalies. Each plot consisted of a square one-quarter-acre inner plot surrounded by a 33-foot-wide buffer. Plot buffers received the same treatment as the plot they surrounded but were not used in data collection. Each tree within a plot was measured for diameter outside bark (inches) at 2, 4.5, and 6 feet above ground level, total height in feet, height to first live branch in feet, and crown width in feet. Presence of fusiform rust (*Cronatium quercuum* f. sp. *fusiforme*), crooks, forks or other defects were also tallied.

After plot boundaries were established and tree data were recorded, each plot was revisited for treatment selection and set-up. Three treatments were installed in a completely randomized, without replacement, factorial design with three replications per treatment. Treatments included three levels of residual densities as measured by Stand Density Index (70, 120, and 170 SDI), two levels of fertilization (fertilized and non-fertilized), and two levels of competition control (herbicide and non-herbicide). For each level of thinning, one plot would receive no fertilization and no competition control; one plot would receive fertilization only; one plot would receive competition control only; and one plot would receive both fertilization and competition control. Six control plots per site that received a standard every third row thin and no other silvicultural treatment were also established.

Residual trees were selected based on the following five criteria, in order of decreasing importance: (1) larger d.b.h., (2) stem form, (3) taller trees, (4) spatial distribution, and (5) crown quality. Selected densities for each plot were calculated using a modified form of Reineke's stand density index (SDI) equation (Zeide 1985):

$$SDI = N\left(\frac{D}{10}\right)^{1.7} \qquad (1)$$

[1]Assistant Professor, Oklahoma State University, Department of Forestry, Stillwater, OK 74078; and Biometrician, Applied Research and Development, Temple-Inland Forest Products Corporation, P.O. Drawer N, 207 N. Temple Drive, Diboll, TX 75941, respectively.

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where, N = number of stems per acre, and D = quadratic mean diameter.

Thinning treatments were conducted in the fall of 1994, and all harvested trees were hauled to area mills. All residual trees in treatment plots were subsequently pruned during the winter of 1994-95 to a height of 25 feet. During the following summer, (1995) each tree was numbered and remeasured. Plots that received competition control were treated by hand spraying of herbicides during the fall of 1995. Herbicide application consisted of a mixture of Arsenol AC, Garlon 4, Red River 90, and surfactant totaling approximately 30 gallons per acre for application. Hardwood trees and shrubs greater than 2 inches in diameter were also "hacked and squirted". In the spring of 1996, fertilization plots were treated with a combination of urea and diamonium phosphate (DAP) giving a blended analysis of 29-17-0. Fertilizer was applied with shoulder mount hand crank spreaders at a rate of 563 pounds per acre. Plots were remeasured during the summers of 1996 and 1998, 2000, and 2002. Individual tree numbers applied during the 1995 measurement cycle allowed tree by tree tracking of increment through 2002.

RESULTS AND DISCUSSION

Pre and post thinning density attributes are shown in table 1. At the 2002 measurement cycle, average diameters ranged from the 8-to 12-inch class and from the high-to low-density classes for both study sites (table 2). For both sites the average diameter increased with decreasing density. Average total tree height ranged from 60 to 67 feet across both sites, with site 1 maintaining consistently taller trees. Within sites, tree heights were within 1 foot of each other with the exception of the control plots.

Growth data were analyzed to determine effect of thinning, fertilization, and competition control on average annual d.b.h. (inches per year) and basal area (square feet per acre per year) increment over the 8-year period from 1995 to 2002. Treatments were tested separately for site 1 and 2 using ANOVA (table 3):

$$Y_{ijkn} = \mu+\alpha_i+\beta_j+\delta_k+(\alpha\beta)_{ij}+(\alpha\delta)_{ik}+(\beta\delta)_{jk}+(\alpha\beta\delta)_{ijk}+\varepsilon_{ijkn} \quad (2)$$

where,

Yijkn = the observed plot increment for the (i,j,k) treatment and nth replication, n = 1,2,3;

Table 1—Density attributes at plot establishment (1994) and post-thin (1995) for study sites 1 and 2

Site	Density class	Density level	Stand density index	Basal area	Stems
				ft² per acre	*trees per acre*
1	Pre-treatment		346.3	166.6	710.5
	Low	1	74.0	35.8	103.7
	Medium	2	121.5	60.1	198.3
	High	3	171.6	83.7	300.0
	Control	4	231.5	111.8	463.3
2	Pre-treatment		274.2	132.4	550.9
	Low	1	74.4	35.8	105.3
	Medium	2	126.8	60.6	190.3
	High	3	176.3	84.2	290.0
	Control	4	196.0	95.1	381.3

Table 2—Average plot attributes by density level for sites 1 and 2 at 2002 measurement

Site	Density level	D.b.h.	Total height	Basal area
		inches	*feet*	*ft² per acre*
1	1	11.9	67.5	73.9
	2	10.2	68.0	106.2
	3	9.2	67.6	128.5
	4	7.9	62.7	142.7
2	1	12.3	63.0	80.1
	2	10.6	63.5	102.2
	3	9.5	63.8	128.5
	4	8.2	60.4	132.6

Table 3—*P*-values associated with the main effects from model (2) for sites 1 and 2

Site	Cultural treatment	*P*-values: D.b.h. increment	*P*-values: BA increment
		inches/year	*ft²/acre/year*
1	Thinning	0.000	0.028
	Fertilization	0.338	0.767
	Comp control	0.658	0.957
2	Thinning	0.000	0.735
	Fertilization	0.194	0.001
	Comp control	0.596	0.818

μ = the true mean of the population;

α_i = the effect of the ith thinning treatment, i = 1,2,3;

β_j = the effect of the jth fertilization treatment, j = 1,2;

δ_k = the effect of the kth competition control treatment, k = 1,2;

( ) = 2- and 3-way interactions between the ith, jth, and kth treatments; and

ε_{ijkn} = error term.

ANOVA indicated significant (α = 0.05) thinning and fertilization effects for diameter increment on both sites 1 and 2. The only other significant difference detected was for the fertilization effect on basal area increment on site 2. No significant two- or three-factor interactions were detected.

For significant treatment effects, one-way ANOVA was used to test for differences in average annual diameter and basal area increment between thinning, fertilization, and competition control treatments for sites 1 and 2. Table 4 indicates cases in which significant differences were detected between increments by site and thinning treatment. The Ryan-Einot-Gabriel-Welch's Multiple Range Test (REGWQ) was used for means separation. REGWQ is used to control the type I experimentwise error rate, while also effectively controlling type II error rates when testing pairwise comparisons (SAS 1989). In addition, REGWQ is more likely to discriminate between nontransitive results, which can frequently occur in multiple comparisons.

Table 5 indicates cases in which significant differences were detected between increments by site and fertilization or competition control treatments. Control plots (thinning density code = 4) were not included in these tests.

D.b.h. Increment

Significant differences were detected between each of the thinning treatments at both sites (table 4). D.b.h. increment was lowest for the highest density control plots and increased with decreasing residual density. Annual growth rates ranged from 0.22 inches per year for controls on site 1 to 0.61 inches per year for thinning treatment 1 on site 1. No significant treatment effects for fertilization and competition control were detected (table 5). However, on both sites the average annual d.b.h. increment was greater for plots that received the treatments than those that did not. Plots of the average d.b.h. and d.b.h. increment by measurement year and cultural treatment also indicate greater response associated with lower residual stand densities along with fertilizer and herbicide application (figs. 1 and 2).

For each thinning treatment, lower residual densities resulted in greater d.b.h. increment. This relationship is attributable to two factors: increased allocation resources to fewer trees as density decreases and the selection of superior trees at the time of plot establishment.

Table 4—Average diameter and diameter increment by site and density level between 1995 and 1998

Site	Density class	D.b.h.[a]	Basal area
		- - - *standard error* - - -	
1	1	0.56a	5.12ab
		(0.01)	(0.36)
	2	0.38b	6.39a
		(0.01)	(0.35)
	3	0.28c	6.14a
		(0.01)	(0.31)
	4	0.22d	4.42b
		(0.01)	(0.36)
2	1	0.61a	5.98
		(0.02)	(0.44)
	2	0.41b	5.39
		(0.02)	(0.78)
	3	0.30c	5.74
		(0.01)	(0.31)
	4	0.24d	5.35
		(0.01)	(0.44)

[a] Means with the same letter within a site are not significantly different using the REGWQ method on all pairwise comparisons.

Table 5—Average annual d.b.h. and basal area increment by cultural treatment for sites 1 and 2. Standard errors are listed below the means in parentheses

		Cultural treatment			
Site	Attribute	Fert[a]	No fert	Comp control	No comp control
1	D.b.h.	0.43	0.39	0.41	0.40
		(0.03)	(0.03)	(0.03)	(0.03)
	BA	5.82	5.95	5.90	5.87
		(0.36)	(0.24)	(0.28)	(0.32)
2	D.b.h.	0.47	0.41	0.45	0.43
		(0.03)	(0.03)	(0.04)	(0.03)
	BA	4.76 a	6.65 b	5.63	5.78
		(0.52)	(0.14)	(0.50)	(0.38)

D.b.h. = diameter increment at breast height (inches per year); BA = basal area increment (square feet per acre per year).

[a] Like letters within the same stand and cultural treatment show no significant difference using Fisher's LSD test at the α = 0.05 level.

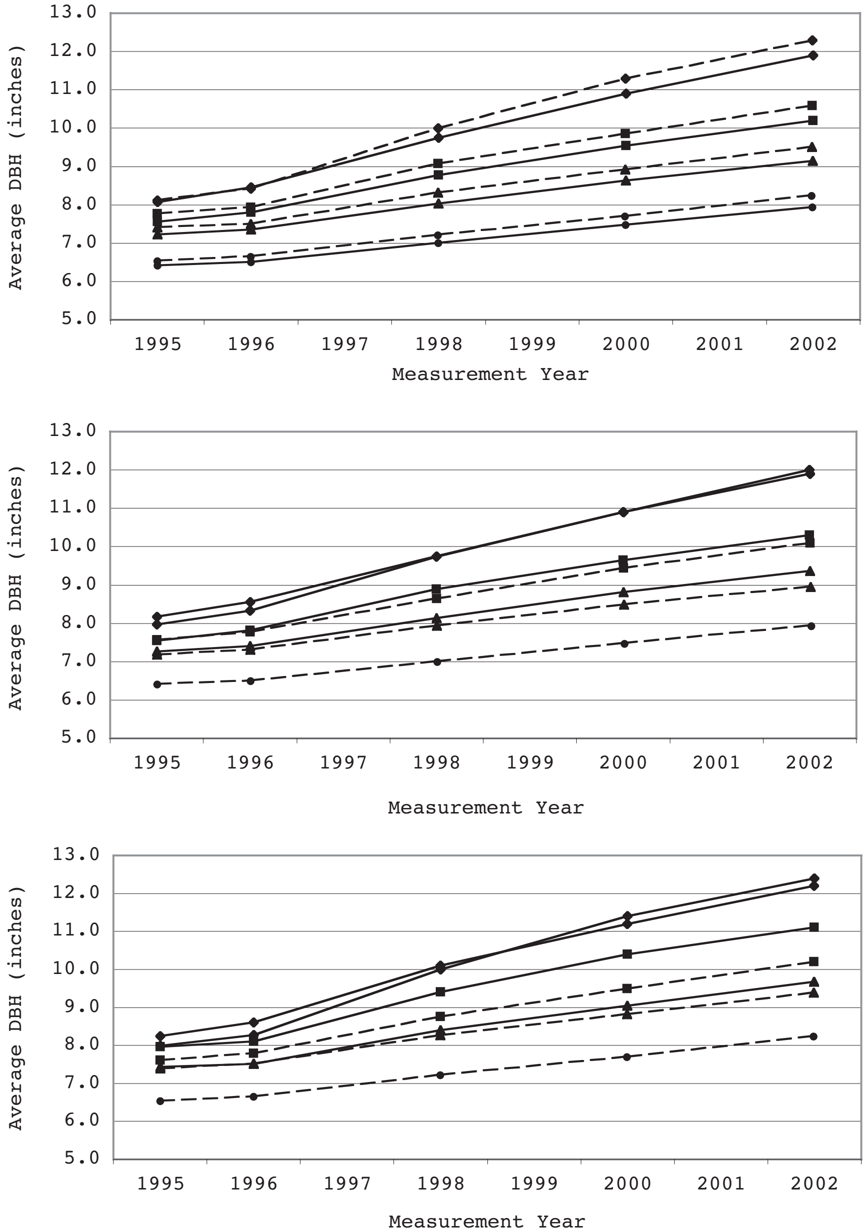

Figure 1—(top) Average d.b.h. plotted against measurement year by study site (Site 1 = solid line and Site 2 = dashed line) and density thinning treatment; (middle) average d.b.h. plotted against measurement year by fertilization treatment (fertilized = solid line and not fertilized = dashed line) and thinning treatment for Site 1; and (bottom) average d.b.h. plotted against measurement year by fertilization treatment and thinning treatment for Site 2. (◆ = density 1, ■ = density 2, ▲ = density 3, and ● = density 4).

Basal Area Increment

A significant difference was detected between thinning treatments for site 1 (table 5). Control plots (thinning treatment 4), which contained the highest residual density and had the lowest average annual basal area increment (4.42 square feet per acre per year), were not significantly different than thinning treatment 1 (5.12 square feet per acre per year), which had the lowest residual density. Also, no significant differences were detected between thinning treatments 1 through 3. Although thinning treatment 2 and 3 were significantly different from treatment 4, no difference was detected between treatment 1 and 4. This non-transitive effect could be the result of slow growth due to over-crowding in the highest density control plots and the low number of trees in the lowest density plots. Thus, although the lowest density class has greater diameter growth, it is putting that growth on so few trees that it is not contributing greatly to the overall basal area per acre. Consequently, the means are not separating from the other density classes.

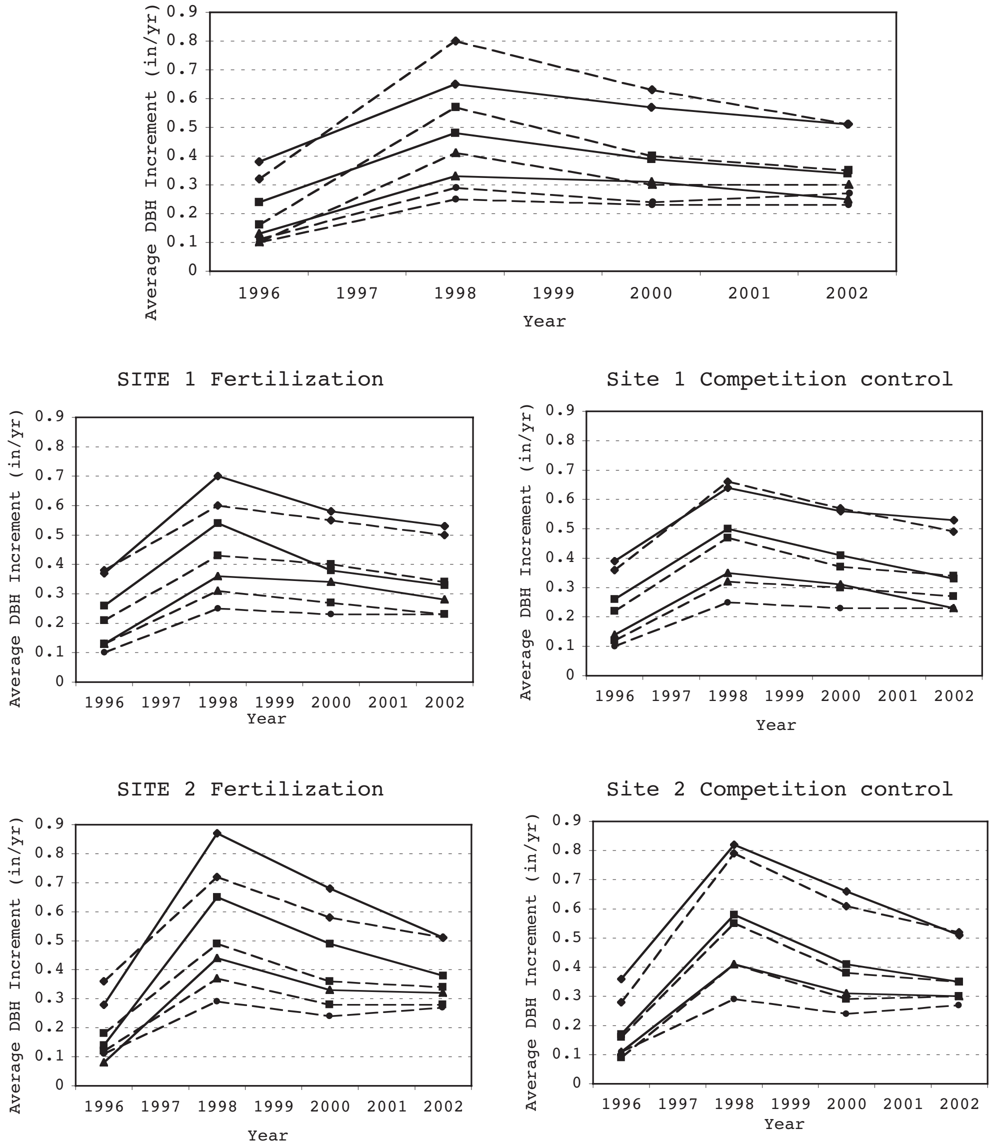

Figure 2—(top) Average d.b.h. increment plotted against measurement year by study site (Site 1 = solid line and Site 2 = dashed line); (middle) average d.b.h. increment for fertilization treatment (fertilized = solid line and not fertilized = dashed line) and competition control treatment (competition control = solid line and no competition control = dashed line), respectively, for Site 1; and (bottom) average d.b.h. increment for fertilization treatment (fertilized = solid line and not fertilized = dashed line) and competition control treatment (competition control = solid line and no competition control = dashed line), respectively, for Site 2. (◆ = density 1, ■ = density 2, ▲ = density 3, and ● = density 4).

A significant difference was detected for the fertilization treatment at site 2. Plots that received fertilizer had significantly lower basal area growth. Although not under the general scope of this paper, the lower basal area growth could be associated with higher than expected mortality associated with the fertilization treatment. Plots of average basal area and basal area increment by measurement year also depict the observed responses associated with cultural treatments (figs. 3 and 4). Note that basal area increment has been increasing or remaining steady for all thinning treatments at site 1, while increasing to a maximum (8 to 10 square feet per acre per year) in 1998 (4 years after treatment) and then sharply decreasing (2 to 5 square feet per acre per year) at site 2.

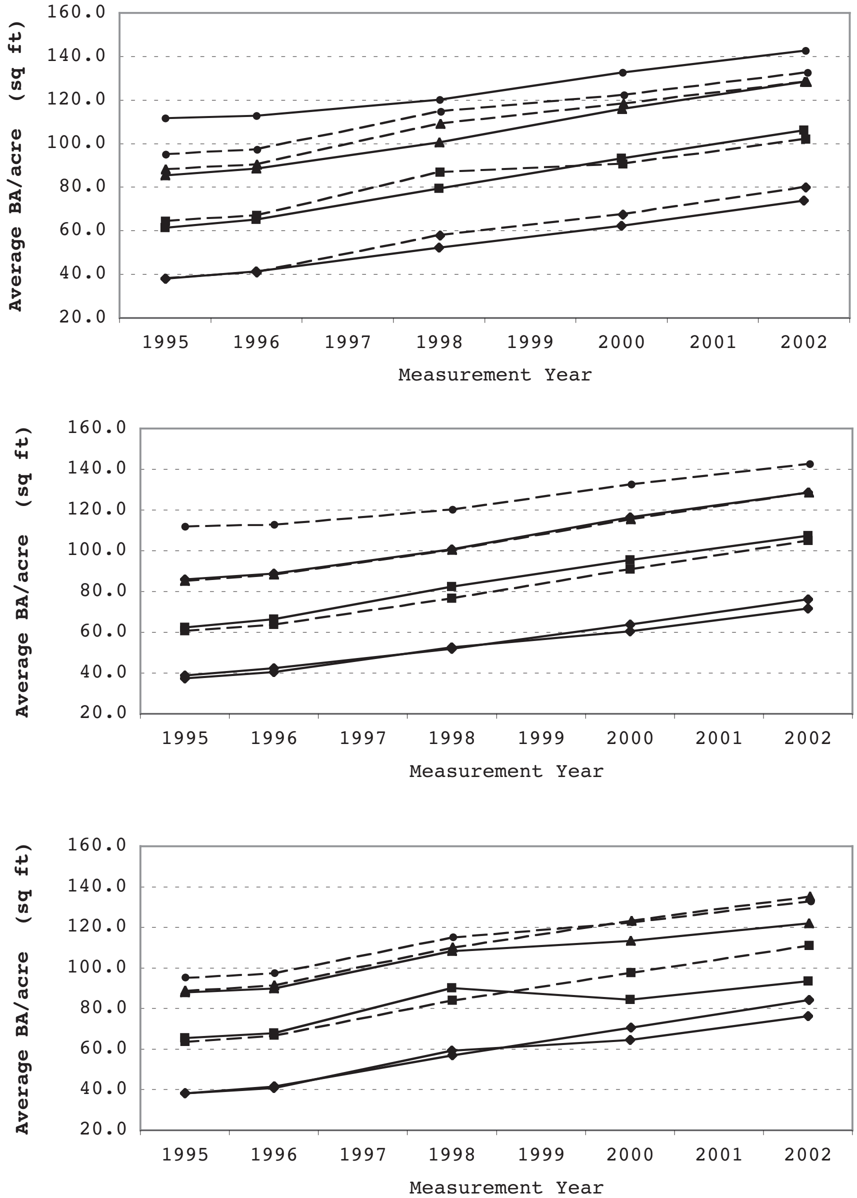

Figure 3—(top) Average basal area per acre plotted against measurement year by study site (Site 1 = solid line and Site 2 = dashed line) and density thinning treatment; (middle) average basal area per acre plotted against measurement year by fertilization treatment (fertilized = solid line and not fertilized = dashed line) and thinning treatment for Site 1; and (bottom) average basal area per acre plotted against measurement year by fertilization treatment and thinning treatment for Site 2. (◆ = density 1, ■ = density 2, ▲ = density 3, and ● = density 4).

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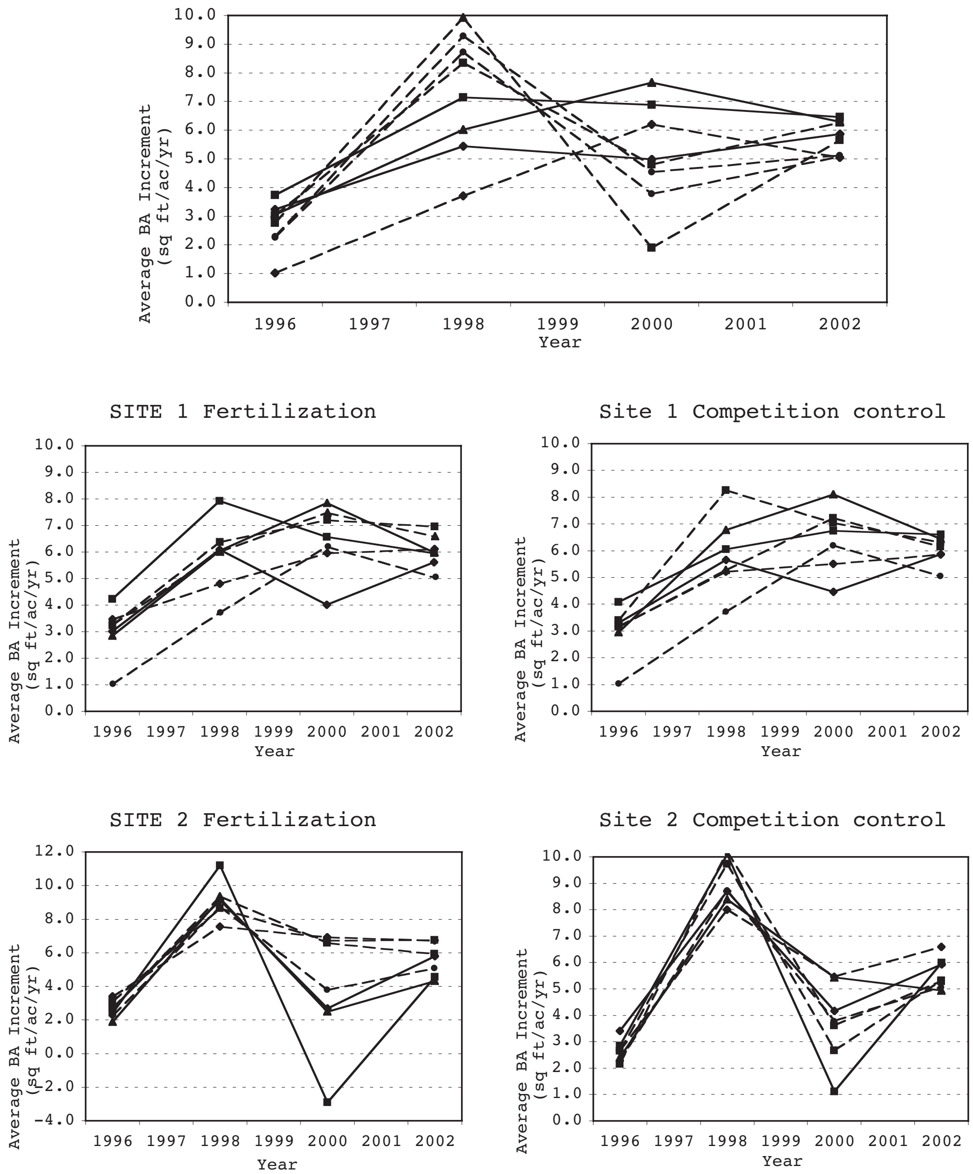

Figure 4—(top) Average basal area increment plotted against measurement year by study site (Site 1 = solid line and Site 2 = dashed line); (middle) average basal area increment for fertilization treatment (fertilized = solid line and not fertilized = dashed line) and competition control treatment (competition control = solid line and no competition control = dashed line), respectively, for Site 1; and (bottom) average basal area increment for fertilization treatment (fertilized = solid line and not fertilized = dashed line) and competition control treatment (competition control = solid line and no competition control = dashed line), respectively, for Site 2. (◆ = density 1, ■ = density 2, ▲ = density 3, and ● = density 4).

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