Growth and Yield Relative to Competition for Loblolly Pine Plantations to Midrotation—A Southeastern United States Regional Study

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ABSTRACT: *Lohlollypine (*Pinus taeda *L.) plantations were studied across 13 southeastern sites grown for 15 yr with near-complete control of woody, herbaceous, and woody plus herbaceous components during the first 3-5 yr. This multiple objective experiment (the COMProject) documents stand dynamics at the extreme corners of the response surface that encompasses most competition conditions common to pine plantations. This is the second of two companion reports. Merchantable pine volume after 15 yr with early, near complete competition control reached 2,350–4,415 ft^3/ac by site compared to I, 132–2,965 ft^3/ac on the no controls. With control of both woody and herbaceous competition, 15 yr volumes were increased by 23-121% and gains increasedas hardwoods andshrubs increased on the no controls. Early woody control increased merchantable pine volume on 1I sites by 14–1 18%, while herbaceous control yielded somewhat less on average, a 17–50% increase on ten sites. No gains and some volume losses occurred when control of one component releasedsevere competition from an enhanced remaining component, otherwise gains were generally additive for control of both components. Pine volume was decreased by about 1% for each 1 ft^2/ac of hardwood basal area (BA) present at age 1.5. Annual measurements detemzined that culmination of current annual increment (CAI) with control of both competition components occurred in yr 8-I I at 250–4 70 ft^3/ac/yr. CAIs for pine height, BA, and volume were decreased by about 5–27% when growing Season rainfall (March–October) was less than 36 in, Mean annual increment had not culminatedfor any treatment at any location by yr 15 and rangedfrom 195–250 ft^3/ac/yr with both woody and herbaceous control. Fusiform rust mainstem galls [*Cronartium quercuum *(Berk.) Miyabe* ex *Shirai* f. sp. fusiforme *(Hedge. & Hunt) Burdsall & Snow] in high severity areas increased additively with control of both components, more so with herb control. Contrary to the widespread assumption that hardwood out-competepine, the hardwoodproportion of stand BA decreasedfrom yr 5-15 on sites where hardwood BA in yr 5 exceeded 10 ft^2. South. J. Appl. For. 27(4):00–00.*

Key Words: *Pinus taeda* L., woody plant control, woody plant competition, hardwood competition, shrub competition, herbaceous plant control, herbaceous competition, forestry herbicides, tree plantation development, merchantablepinevolume, current annual increment, mean annual increment, rainfall influence on productivity, competition threshold, fusiform rust, *Cronartium quercuum*.

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The juvenile growth of loblolly pine is accelerated by early herbaceous and longer term woody competition reductions (Cain and Mann 1980, Nelson et al. 1981, Zutter et al. 1986, Bacon and Zedaker 1987, Glover et al. 1989, Fredericksen et al. 1991, Haywood 1994, as examples). There are many reports of early increased growth of loblolly pine plantations after competition control; however, there are few reported long-term outcomes after stand closure. Most growth and yield projections assume that early gains continue through midrotation or longer, but few longer term findings (greater than 12 yr) have been reported to substantiate or refute this assumption (Clason 1989, Haywood and Tiarks 1990, Glover and Zutter 1993). In fact, positive longer term growth gains associated with competition control have been questioned by research findings that do not present competition levels (Haywood and Tiarks 1990, Jokela et al. 2000). Both pine and associated plant data are both needed to learn fully how stand and site characteristics alter competition dynamics and plantation succession. Furthermore, to learn how the interaction of plantation stands and site characteristics alter competition dynamics, it is essential to study both pine and competing plants from many locations established using the same study protocol. To gain a needed regional perspective, strategically locatedstudysiteswithinarangeofphysiography, topography, and commonly occurring soil sites are required.

Another limitation of current knowledge is the understanding of how competition components ofwoody and herbaceous vegetation interact to alter long-term plantation development and wood yields. Too often, studies fail to quantify thecompetition components and their level ofcontrol so that competition-crop interferences can be analyzed relative to early stand treatments (Jokela et al. 2000, Borders and Bailey 2001). Important to this understanding is the need to use near-absolute competition control at each location so that responses to other treatments can be appropriately scaled and compared across sites in relative (site quality equalized) as well as absolute terms. These data and understandings are needed to guide management refinements aimed towards developing productive sustainable plantation culture and to provide baseline data for furthering forest vegetation management science. Such information needs become more urgent when it is realized that pine plantations currently occupying 15% of southeastern forestlands may occupy 26% by 2040 (Wear and Greis 2002).

Still another serious omission in our understanding of plantation development is data showing trends in the current and mean annual increments for pine plantations, and changes by intensive cultural practices. Absolutely no measured patterns of annual growth (i.e., current annual increment) have been published for loblolly pine (or for any other conifers worldwide); only Cain (1978) has provided biennial periodic annual increments for one mechanically prepared loblolly pine site. Without details on patterns of annual growth for conifer plantations relative to vegetation control treatments and weather influences, little can be done to improve vegetation control strategies, growth and yield models, predictions of climate change impacts, and projections of pine wood availability in regions using intensive silviculture.

Existing growth and yield models for loblolly pine plantations have functions for hardwood competition that rely on assumptions not yet fully tested. Burkhart and Sprinz (1984) assumed that the proportion of hardwood BA to total stand BA remained constant over time, in their development of Model HDWD. They relied on data from one long-term study in the Hilly Coastal Plain of northwest Alabama with high hardwood levels that displayed this behavior(Gloverand Dickens 1985). In another approach, Smith and Hafley (1987) assumed that hardwood proportions decreased with time when they developed the North Carolina State University Plantation Management Simulator. Smith and Hafley based their assumption on measurements of hardwood resprout stands in the Piedmont of South Carolina ranging from 5-39 yr (Zahner and Myers 1984). In a later report, Smith et al. (1989) provided further substantiating data for Virginia on mixed pine-hardwood stands measured from yr 4-19. Data from theserelatively high hardwood sites showed aproportional decline in hardwood BA from yr 7-15 followed by constancy in proportion. A broader testing of these critical assumptions is needed to support future modeling efforts forthe region, and the data reported here provide this.

To address data omissions and to evaluate critical assumptions a group of investigators with university, industrial, and USDA Forest Service (Southern Research Station) cooperators established a region-wide study termed the Competition Omission Monitoring Project (COMProject or COMP) in 1984. This research project employs a unified protocol that continues to examine loblolly pine plantation development relative to four, near-absolute, early competition control treatments (Miller et al. 1987, 1991, 1995aand1995b, Zutteretal. 1995,ZutterandMiller 1998). Thedesign isolates the influences of the two major competition groups-woody and herbaceous plants-and documents their long-term interaction with uniformly established pine. The aim was to study outcomes relevant to intensifying practices ofplantation establishment in the region, and to explore the limits of pine plantation productivity following intensive early competition control. This 15 yr analysis ofthe data and synthesis examines patterns ofplantation stand development from both silvicultural and plant successional perspectives and summarizes the results in two companion reports (Miller et al. 2003 *this issue).*

The study objectives examined in this second part of the companion reports are:

1. To quantify the relative and absolute effects of woody vs. herbaceous vegetation control on pine growth and volume yield, describing annual increments of early growth.
2. To determine maximum potential growth of loblolly plantations without fertilization following complete early control ofwoody, herbaceous, and woody plus herbaceous plants.
3. To describe in detail the relationship between pine and woody competition including a test for the assumption that hardwood BA remains at a constant proportion of plantation BA once an initial establishment phase is completed.

Methods

A common study design was utilized at 13 plantation sites in seven states and across four physiographic provinces of the Southeast. Research methods are described fully in the companion report, Miller et al. (2003 *p. XXX*). Pertinent details are summarized here.

Immediately prior to establishment, pine plantations or mixed pine-hardwood stands had been harvested. At ten locations, site preparation was by roller-drum chopping and prescribed burning. With similar outcomes, a shear, pile, and bum method was used at Counce, TN, while at Atmore, AL, a complete harvest of fuelwood and pine was used without prescribed burning. The Lower Coastal Plain site near Pembroke, GA was rebedded after a wildfire destroyed a young plantation.

A factorial combination of two woody control treatments (no woody control vs. woody plant elimination) and two herbaceous control treatments (no herbaceous control vs. herbaceous plant elimination) wereestablished, that is: (1) No Control after site preparation; (2) Woody Control; (3) Herb Control; and (4) Woody and Herbaceous Control (denoted as W+H Control). Preplant and multiyear postplant herbicide treatments for the first 3-5 yr were used to establish and maintain the treatment situations. Treatment plots were generally 0.25 ac in size, and interior measurement plots were 0.09 ac. Precisely measured planting spots on a 9 x 9 ft spacing were used at all but the operationally planted locations of Pembroke, GA and Arcadia, LA. This spacing resulted in 538 treeslac (565 and 622 treeslac at the operationally planted locations), with 49 pines in the measurement plots and two border rows surrounding the measurement plots.

At most sites, two 1-O loblolly pine seedlings (regraded on site for larger size) were planted at each spot, 10–12 in. apart. First-generation genetically improved seedlings were used at all locations. After the first growing season, double-planted seedlings were thinned to one per spot. Initial sizes are reported in Miller et al. (1995b).

Measurements and Calculations

Pines were measured for total height (nearest 0.1 ft) in yr 1-l 1 and 15. Foreachmeasurement year, thepresenceofgalls on the mainstem from fusiform rust and mortality judged due to fusiform were recorded. Diameters at breast height (dbh) were measured to the nearest 0.1 in. from yr 3-l 1 and 15. Basal area (BA) was calculated by summing the stem area at breast height for all surviving trees. For yr 3-8 (before merchantability), a volume index was calculated for each pine using $(dbh^2 \times height)/3$, where both dbh and height are in feet. Merchantable tree volume outside bark (to a 4 in. top) for yr 3-l 1 and 15 was calculated according to equations by Tasissa et al. (1997) for unthinned loblolly pine and summed for all surviving trees in ft^3/ac/yr. These volumes were divided by 80 to derive cord equivalents. Basal area and tree volumes were expanded to an acre basis by multiplying by the appropriate expansion factor for the measurement plot. Current annual increments (CAI) were calculated for each site using the annual measurements for yr 1-l 1 and periodic annual increments (PAI) were calculated between yr 11 and 15. Site index (age 25 basis) was calculated for each location using mean heights of the tallest 300 stems/ac at age 15 for the No Control treatments and curves for site-prepared loblolly pine developed by Burkhart et al. (1987).

All hardwood rootstock stems exceeding 4.5 ft in height within each interior measurement plot were recorded after growing seasons 5, 8, 11, and 15 by species, dbh class (0.5 in. classes) and height class (i.e., classes were 1 ft intervals through 12 ft, and 5 ft intervals thereafter). Hardwood BA and sum of stem heights were calculated for each plot.

Rainfall data for the study period were obtained from the nearest NOAA weather station to each site. Stations ranged from 0.5-l 8 miles away (average = 7 miles). For the first 15 yr, "growing season rainfall" for the months of March through October was calculated for each location and year.

Analyses

To aid in summarization and interpretation, locations were grouped into woody competition categories. Groupings were developedusing SAS Cluster Analysis basedonyr 15 hardwood BA and shrub sum of rootstock heights (see Figure 2 in companion paper, p. XXX). Three woody competition categories clearly delineated were: Low Hardwood BA (four locations), High Hardwood BA (seven locations), and High Shrub (two locations). These groupings were not discemable until yr 15, although a retrospective examination showed that Low Hardwood BA and High Shrub locations had less than 1,800 hardwood rootstocks/ac at yr 1. Average site indices for the three woody competition categories were similar for Low and High Hardwoods at 69.5 and68.6 ft, respectively, but somewhat lower for High Shrubs at 63.5 ft (see header Table 1).

Pine and competition data were analyzed separately by location using the appropriate analysis of variance (ANOVA) following arcsine squareroot transformations for percent values. The main effects were defined as woody treatment (average of Woody Control and W+H Control vs. average of No Control and Herb Control), herbaceous treatment (average of Herb Control and W+H Control vs. average of No Control and Woody Control), and the woody x herbaceous interaction (average of W+H Control and No Control vs. average of Woody Control and Herb Control). Tukey's HSD test was used to separate treatment means for critical examination of selected variables. A 0.05 level of probability for a Type I error was considered significant with all tests, while 0.01 levels were noted. References in the text to effects of woody treatment or herbaceous treatment refer to tests of main effects from the ANOVA, whereas references to No Control, Woody Control, Herb Control, or W+H Control refer to the four treatments within the study design. Linear regression analysis was used to examine relationships between pine volume and hardwood BA grown with and without herbaceous competition control. Analyses for homogeneity of regression coefficients were also calculated using SAS.

Results

Pine Response to Treatment

Pine density averaged from 354-524 trees/ac after 15 yr and was comparable for most locations and treatments, except

Table 1. Mean pine attributes at age 15 by vegetation control treatment with sites grouped by woody competition category, and the ANOVA outcomes with main effects and their interaction in bold italics (values are significant differences attributed to treatment and significance of interaction).

	Low hardwood BA						High hardwood BA					High shrub	
Control *ANOVA*[1] *Results*	Jena LA MCP[2] SI=73[3]	Counce TN HCP 63	Warren AR HCP 65	Monti-cello GA Pied 77	Liver-pool LA MCP 69	Arcadia LA HCP 66	Liberty MS MCP 77	Bain-bridge GA MCP 82	Camp Hill AL Pied 67	Tallassee AL HCP 62	Appo-mattox VA Pied 57	Pem-broke GA LCP 60	Atmore AL MCP 67
Trees/ac													
No	472	524	518	485	504	499	354	494	488	505	447	520	504
Woody	447	521	524	483	521	511	365	494	479	494	398	511	483
Herb	491	510	521	475	480	483	417	490	472	483	359	506	414
W + H	507	516	515	512	491	510	414	502	472	510	417	508	483
Woody	***n.s.***[4]	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***
Herb	***+40****	***n.s.***	***n.s.***	***n.s.***	***–27****	***n.s.***	***+56*****	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***–45****
W × H	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	*****
Height (ft)													
No	48.8	42.1	42.8	51.2	45.3	44.3	52.0	53.7	45.2	41.4	38.6	38.7	44.2
Woody	47.9	43.1	46.1	51.7	45.6	46.3	55.7	53.9	47.9	44.1	43.1	45.7	48.8
Herb	51.2	44.4	47.7	54.6	49.5	41.9	58.9	54.6	44.5	39.0	40.3	44.4	47.0
W + H	53.0	46.0	48.9	53.6	52.1	51.3	59.8	58.4	52.9	50.0	45.7	47.1	52.7
Woody	***n.s***	***+1.3****	***+2.2****	***n.s.***	***n.s.***	***+2.7*****	***+2.3****	***+2.0****	***+5.5*****	***+6.9****	***+5.0*****	***+4.9*****	***+5.1*****
Herb	***+3.7*****	***+2.5*****	i-3.8**	***+2.6*****	***+5.3*****	***+4.3*****	***+5.5*****	***+2.7****	***n.s.***	***n.s***	***n.s.***	***+3.5*****	***+3.3*****
W × H	***n.s.***	***n.s.***	***n.s***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	*****	***n.s***	***n.s.***	***n.s.***	***n.s.***
Dbh (in.)													
No	7.3	6.8	7.0	7.1	6.2	6.7	7.2	6.8	6.5	6.0	5.8	5.3	5.7
Woody	7.2	7.0	7.5	7.3	6.6	7.1	8.4	7.1	7.1	6.7	7.7	6.3	6.6
Herb	7.5	7.0	7.6	7.8	6.9	7.0	7.9	6.8	6.1	5.3	6.0	6.2	6.2
W + H	7.6	7.5	7.9	7.6	7.5	7.7	8.6	7.7	8.0	7.5	8.3	6.4	7.5
Woody	***n.s.***	***+0.4*****	***+0.4*****	***n.s.***	***+0.5*****	***+0.6*****	+o. ***9*****	***+0.6****	***+1.3*****	***+1.5*****	***+2.1*****	***+0.6*****	***+1.1*****
Herb	***n.s.***	***+0.4*****	***+0.5*****	***+0.5*****	***+0.8*****	***+0.4*****	***+0.4****	***n.s.***	***n.*** s.	***n.s.***	***n.s.***	***+0.5*****	to. ***7*****
W × H	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s***	***n.s.***	***n.s.***	***n.s.***	******	*****	***n.s.***	***n.s.***	***n.s.***
Pine basal area (ft^2/ac)													
No	143	136	144	138	113	128	105	131	116	101	87	83	95
Woody	132	143	164	147	131	147	144	141	135	123	134	115	119
Herb	155	143	170	164	132	135	147	129	101	83	89	III	93
W + H	171	161	184	176	157	175	170	166	166	165	159	122	155
Woody	***n.s.***	***+12*****	***+17*****	. ***n.s.***	***+22****	***+30*****	***+31*****	***+24****	***+42*****	***+52*****	***+59*****	***+22*****	***+43*****
Herb	***+26*****	***+12*****	***+23*****	***+27*****	***+23****	***+18*****	***+34*****	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***+18*****	***+17****
W × H	***n.s.***	***n.s.***	***n.s.***	***n.s.***	***n.s.***	*****	***n.s.***	***n.s.***	******	******	***n.s.***	***n.s.***	***n.s.***
Pine merchantable volume OR ($ft^3/acre$)													
No	2,965	2,380	2,590	2,944	2,028	2,338	2,318	2,907	2,113	1,591	I.287	1,132	1,585
Woody	2,662	2,568	3,207	3,212	2,48 I	2,834	3,482	3,175	2,695	2,261	2,500	2,092	2,373
Herb	3,341	2,633	3,463	3,827	2,764	2,695	3,704	2,909	1,778	1,247	1,367	I ,970	1,162
W + H	3,856	3,134	3,838	4,010	3,443	3,81 I	4,415	4,125	3.766	3,479	3.185	2,350	3,498
Woody	***n.s.***	***+344*****	***+496*****	***n.s.***	***+566*****	***+806*****	***+937*****	***+742****	***+1,285*****	***+1,451*****	***+1,515*****	***+670*****	***+1,262*****
Herb	***+785*****	***+409*****	***+752*****	i-841 **	***+849*****	***+667*****	***+1,159*****	***n.s.***	***n.s.***	***+437****	***n.s.***	***+548*****	i-651 **
W × H	******	***n.s.***	***n.s.***	***n.s.***	***n.s.***	*****	***n.s.***	***n.s.***	*****	******	***n.s.***	***n.s.***	*****

(continued)

for herbaceous treatments at four locations (Table 1). Herbaceous treatments resulted in 40 and 56 more trees/ac at Jena, LA and Liberty, MS (a single planted site), respectively. These main effect outcomes actually resulted from reduced survival on Woody Controls due to severe competition from woolly croton (*Croton capitatus* Michx.)—a residual row-crop weed in the seed bank-and broomsedge *(Andropogon)*, respectively. At Liverpool, LA and Atmore, AL, herbaceous control treatments averaged 27 and 4.5 fewer tree/ac, respectively. This mortality was likely due to early competition from high levels of both hardwoods and shrubs that were released on the Herb Control plots, indicated by the high yr 15 levels (see Table 2 in companion paper, p. XXXX). Pine densities at yr 15 varied by an average of only 7% between the

Table 1. (continued)

	Main stem fusiform rust (%)[5]												
No	0.5	1.0	2.6	14.8	2.5	1.4	12.8	22.5	10.7	8.2	0	5.9	6.1
Woody	1.5	1.5	2.6	18.4	7.1	4.1	9.2	28.6	15.7	4.1	0	9.2	4.1
Herb	1.0	2.0	3.6	21.4	7.2	1.6	13.3	33.3	15.9	19.4	0.5	14.8	8.7
W + H	0.5	1.0	2.5	29.6	11.7	8.8	17.9	50.0	22.5	29.6	0	23.1	27.1
Woody	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*+11.4**	*+5.8**	*n.s.*	*n.s.*	*+5.8***	*n.s.*
Herb	*n.s.*	*n.s.*	*n.s.*	*+8.9***	*n.s.*	*+5.5***	*n.s.*	*+16.1***	*n.s.*	*+18.4**	*n.s.*	*+11.4***	*+12.8***
W × H	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*

The main effects of woody treatment (average of Woody Control and W + H Control minus average of No Control and Herb Control), herbaceous treatment (average of Herb Control and W + H Control minus average of No Control and Woody Control), and their interaction (average of W + H Control and No Control minus average of Woody Control and Herb Control).

[2] Physiographic province: LCP = Lower Coastal Plain, MCP = Middle Coastal Plain, HCP = Hilly Coastal Plain, and Pied = Piedmont.

[3] Site index base age 25 calculated using the tallest 300 trees per acre using curves by Burkhart et al. (1987).

[4] n.s.= nonsignficant at $P = 0.05$, * = significant at $P < 0.05$, and ** = significant at $P < 0.01$.

[5] Includes incidence of mainstem fusiform rust at age 15 plus mortality recorded from mainstem fusiform rust during 15 years.

highest and the lowest density by treatments at any one site.

Early competition control continued to have a significant positive influence on pine height, dbh, BA, and merchantable volume at yr 15 (Table 1). After 15 yr, pine heights by treatments averaged across sites (with ranges) were45 ft (39-54 ft) forNo Controls, 48 ft (43-56 ft) for Woody Controls, 48 ft (39-59 ft) for Herb Controls, and 52 ft (46-60 ft) for W+H Controls. For comparison, hardwood rootstock heights averaged across locations were 17 ft (1 O-23 ft) forNo Controls, 11 ft (7-14 ft) for Woody Controls, 20 ft (1 l-26 ft) for Herb Controls, and 4 ft (O-9 ft) for W+H Controls (data not shown). Hardwoods were predominantly midstory and understory in No and Herb Control stands, while the ingrowth on Woody and W+H Controls remained essentially in the understory.

For pine height response, ten locations had significant increases with woody treatments by yr 15, ranging from 1.3 ft at Counce, TN (Low Hardwood BA site) to 6.9 ft at Tallassee, AL(HighHardwoodBA site)—different categories but similar site indices (63 and 62, respectively). Herbaceous treatments also had significant height increases at ten locations, ranging from 2.5 ft at Counce, TN to 5.5 ft at Liberty, MS (High Hardwood site, SI = 77). Height differences between No Controls and W+H Controls were significant for all locations as judged by Tukey's HSD test. Gains with W+H Control over No Controls averaged 4.1 ft for Low Hardwoods, 7.1 ft for High Hardwoods, and 8.5 ft for High Shrubs and increased as woody competition components and abundance increased.

On Low Hardwood BA sites, Herb Control yielded more rapid height growth than Woody Control and was comparable to W+H Control for the first 4 yr (Figures 1 and 2). On these sites, height gains with W+H and Herb Control over No Control culminated in yr 8 and declined through age 15 (Figure 2). Mean height gains for Woody Control over No Control on these Low Hardwood BA sites never exceeded 2

Table 2. Linear correlation coefficients (top value) and probabilities (bottom value) for woody competition measures and pine merchantable volume, merchantable volume loss relative to W + H Controls, and percent reduction in merchantable volume relative to W + H Controls at age 15 for the No controls and Herb controls, with and without High shrub (HS) sites.

Wbody competition measures	Pine merchantable volume		Merchantable volume loss		Percent merchantable volume loss	
	w/ HS	w/o HS	w/HS	w/o HS	w/HS	w/o HS
	(ft³/ac)					
No control						
Hardwood BA (ft^2/ac)	-0.254 0.4022	-0.742 0.0090	0.726 0.0050	0.869 0.0005	0.532 0.0610	0.901 0.0002
Percent hardwood BA	-0.381 0.1990	-0.804 0.0029	0.791 0.0013	0.882 0.0003	0.643 0.0178	0.938 0.0001
Sum of woody heights (ft/ac)	-0.771 0.0018	-0.699 0.0168	0.668 0.0127	0.756 0.0071	0.833 0.0004	0.789 0.0038
Herb control						
Hardwood BA (ft^2/ac)	-0.529 0.0628	-0.717 0.0129	0.849 0.0002	0.879 0.0004	0.882 0.0008	0.854 0.0008
Percent hardwood BA	-0.681 0.0103	-0.829 0.0016	0.933 0.0001	0.943 0.0001	0.916 0.0001	0.937 0.0001
Sum of woody heights (ft/ac)	-0.583 0.0364	-0.611 0.0456	0.815 0.0007	0.814 0.0023	0.166 0.0023	0.753 0.0074

[1] Combined sum of hardwood stem heights and shrub rootstock heights.

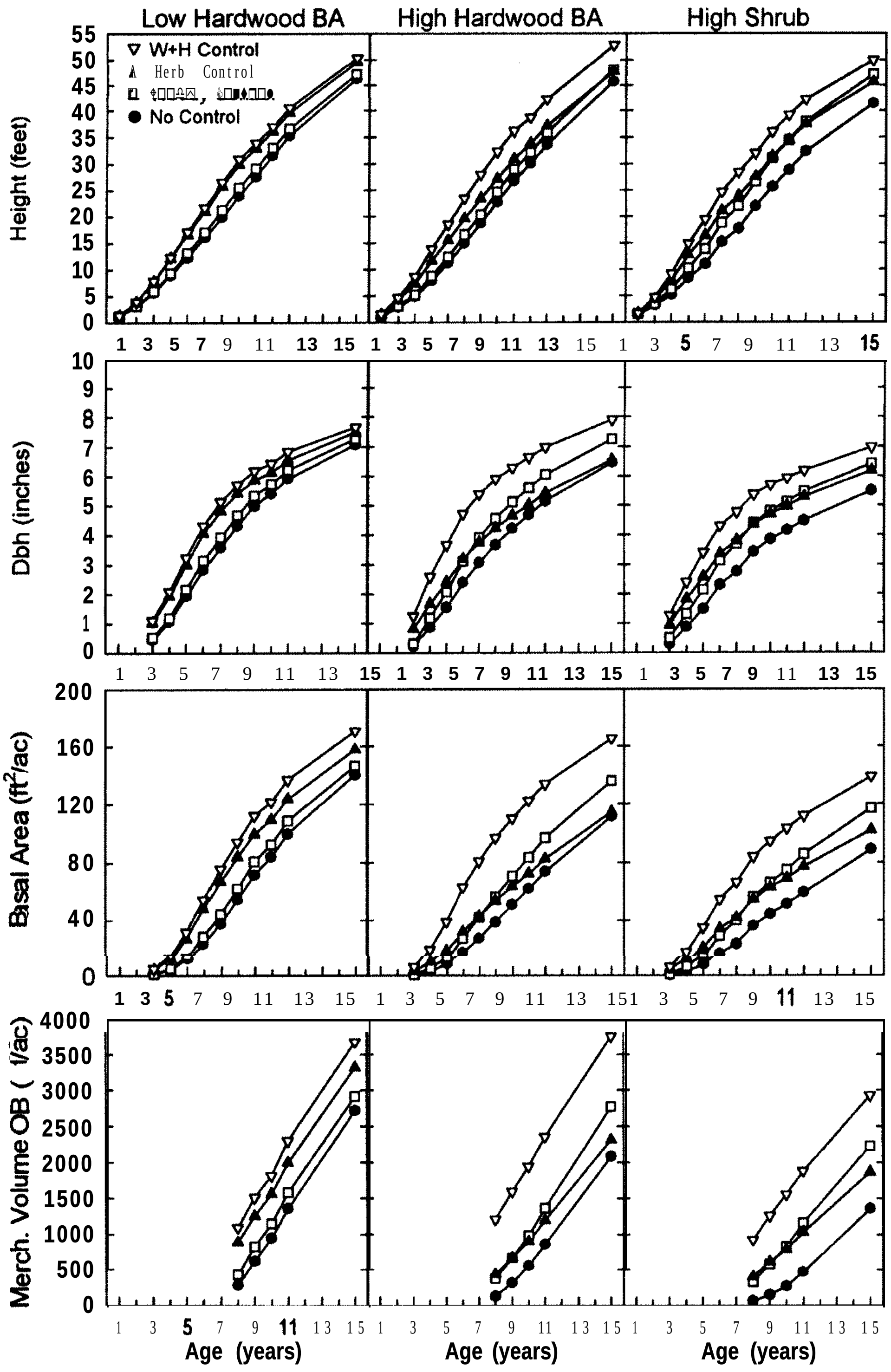

Figure 1. Mean pine height, dbh. basal area, and merchantable volume through 15 growing seasons by woody competition category and vegetation control treatment.

ft and culminated in yr 9 (Figure 2). On High Hardwood BA and High Shrub sites the relative height gain with Woody Control has remained mostly constant after yr 9, being more than twice as great on High Shrub sites compared to High Hardwood BA sites (Figure2). Overall height gains with Herb Control were not that different among woody categories, while gains with Woody Control were in the order High Shrub > High Hardwood > Low Hardwood. Except for Woody Controls on High Hardwood BA and High Shrub sites, treatment-induced height gains over No Control declined as stands developed (Figure 2).

Pine diameters in yr 15 averaged across sites (with ranges) were 6.5 in. (5.3-7.3 in.) for No Control, 7.1 in. (6.3-8.4 in.) for Woody Control, 6.8 in. (6.0-7.9 in.) for Herb Control, and

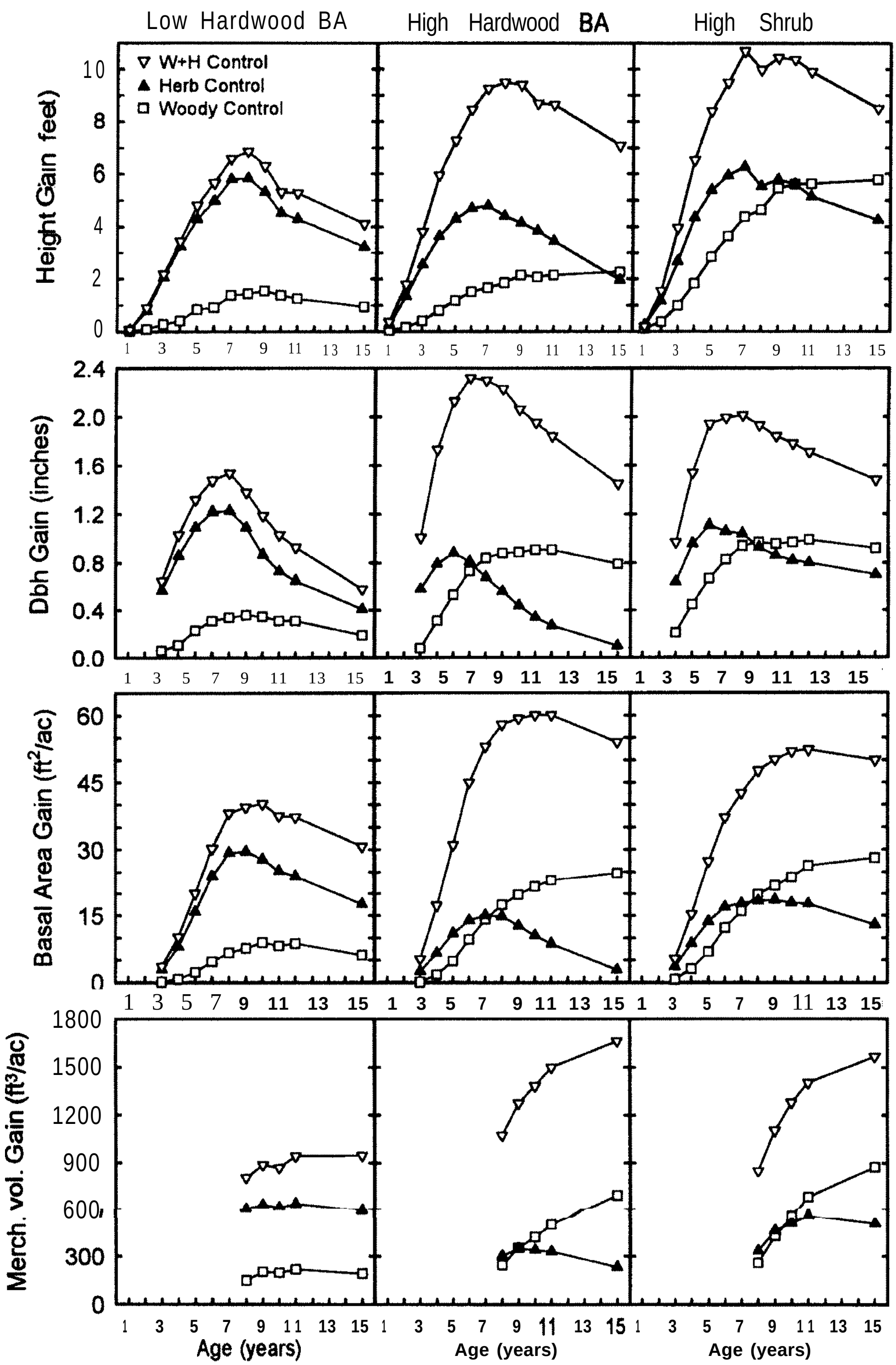

Figure 2. Gain in pine height, dbh, basal area, and merchantable volume over the No Control treatment through 15 growing seasons by woody competition category and vegetation control treatment.

7.7 in. (6.4–8.6 in.) for W+H Control. By yr 15, pine diameters differed significantly with woody control treatments at 11 locations resulting in increases of 0.4–2.1 in. (Table 1). Gains were greatest on those High Hardwood BA sites having the greatest hardwood BA. Herbaceous control treatments had significant diameter responses at eight locations, ranging in increases from 0.4-0.8 in. On Low Hardwood BA sites, diameter gains from early herbaceous control were equal or greater than those with woody control treatments (Table 1). Herbaceous treatments on the highest hardwood sites resulted in no diameter gain by yr 15, i.e., Bainbridge, GA; Camp Hill, AL; Tallassee, AL; and Appomattox, VA (Table 1).

Dynamic gains in pine dbh with Herb Control relative to No Control were greatest in yr 5 on High Hardwood and High Shrub sites, and in yr 6-7 on Low Hardwood sites (Figure 2). Gains in dbh over No Controls declined for all treatments and sites (Figure 2) as dbh growth decreased (Figure 1). The dbh gains in yr 1.5 for W+H Control over No Control averaged 0.6 in. for Low Hardwoods (+8%), 1.4 in. for High Hardwoods (+22%), and 0.9 in. for High Shrubs (+17%). Maximum differences between W+H Controls and No Controls occurred on average in yr 7 or 8 at 1.5 in. for Low Hardwoods, 2.3 in. for High Hardwoods, and 2.0 in. for High Shrub (Figure 2).

Average pine BA ranged from 83-l 84 ft^2/ac at yr 15 across sites and treatments (Table 1). Significant gains with woody treatments occurred on 12 sites and averaged 12-59 ft^2/ac, while gains with herbaceous treatments occurred on nine sites and averaged 12-34 ft^2/ac. On High Hardwood BA and High Shrub sites, the significant main effects and their magnitude generally indicategreatergains with Woody Control compared to Herb Control. On Low Hardwood BA sites, Herb Control yielded greater average BA gains than Woody Control (Figure 1 and 2). But on the highest hardwood sites, Herb Control had no lasting effect on pine BA (Table 1).

Basal area gains by yr 1.5 for W+H Control over No Control (all sites significantly different according to Tukey's HSD test) averaged 33 ft^2/ac for Low Hardwoods (+23%), 54 ft^2/acre for High Hardwoods (+49%), and 50 ft^2/acre for High Shrubs (+56%)—much larger percent increases as compared to diameters. Pine BA gains from Woody Control for High Hardwood BA and High Shrub sites continue to increase, although slightly, through yr 15 (Figure 2). Basal area gains for Herb Controls declined in a similar manner to diameters. Compared to diameters, peak divergence in BA forNo Controls and W+H Controls occurred 2 yr later for Low Hardwoods (yr 8-9) and 4 yr later for High Hardwoods (yr 10) and High Shrubs (yr 11).

Merchantable Volume Gains

Merchantable volume at yr 15 differed significantly among treatments, with gains of 344-l ,5 15 ft^3/ac for woody control treatments on 11 sites and gains of 409–1,159 ft^3/ac for herbaceous control treatments on ten sites (Table 1). The nonsignificant interactions at eight locations indicate these gains were generally additive for woody and herbaceous control. As with the other pine response variables, herbaceous treatments on Low Hardwood BA sites yielded greater average volume gains than woody treatments, and woody control had greater than average effect on High Hardwood BA and High Shrub sites. On four of the highest hardwood sites, Herb Controls did not differ from No Controls according to Tukey's HSD test, and had less or comparable growth (Table 1).

The dynamics of merchantable volume development were different for the four treatments and the three woody competition categories (Figure 1). On Low Hardwood and High Hardwood sites, W+H and Woody Control volume development was similar in magnitude and rate, while volume development was slower and less for Herb and No Controls on High Hardwood sites (Figure 1). Slower but relatively similar patterns of volume development occurred on High Shrub sites compared to High Hardwoods for W+H and Woody Controls (Figure 1). On High Shrub sites, merchantable volume at yr 1.5 on W+H Controls was about double that of No Controls. No Controls on High Shrub sites had the greatest proportional lossinpinevolumethan theotherwoodycategories,suggesting that the addition of the high shrub component in combination with herbaceous and hardwood competition detracted a greater proportion of growth on these sites.

Gains in yr 15 merchantable volume for W+H Control over No Control (all sites being significantly different according to Tukey's HSD test) averaged 990 ft^3/ac for Low Hardwoods (+36%), 1,663 ft^3/ac for High Hardwoods (+80%), and 1,565 ft^3/ac for High Shrubs (+115%). Volume gains over No Controls continued to increase for W+H and Woody Control on High Hardwoods and High Shrubs, while gains on Low Hardwoods remained constant to slightly declining by yr 15 (Figure 2). After yr 9, gains on High Hardwood and High Shrub sites from Woody Control exceeded those from Herb Control, but remained much less than W+H Controls.

Vegetation Control and Fusiform Rust

Fusiform rust galls on pine mainstems occurred at all locations (Table 1), with the severity generally following historical patterns for this disease in the region (Squillace 1976). In areas of high rust incidence, mainly in Georgia and Alabama, trees on W+H Controls had the highest infection rate of the four treatments. W+H Controls had significantly more infection than No Controls at seven locations as determined by Tukey's HSD test. Woody control treatments were associated with a significantly increased incidence at three sites, according to the ANOVA, where 6-l 1% more trees in treated plots had mainstem galls or died from infection. Six locations had significantly more fusiform after herbaceous control treatments (one significant interaction), with an increased incidence of 5-l 6%. Highest infection occurred at Bainbridge, GA where half the trees on W+H Controls had mainstem galls. The half-sibling family planted at the Bainbridge site has since been identified as highly susceptible to fusiform rust (pers. comm., Charles Hollis, retired International Paper, September 24, 1990).

Proportion of Hardwood Competition Over Time

On the majority of sites, the proportion of hardwood BA to total stand BA (hardwood + pine) was not constant through the first 15 growing seasons (Figure 3), contrary to assumptions used in some current growth-and-yield models. The proportion declined from yr 5-8 on both No and Herb Control treatments on all except the sites with the lowest hardwood BA. Sites with over 40% hardwood BA at age 5 continued to decline from yr 8-11. Only on sites with less than 10% hardwood BA was some degree of constancy in proportion maintained from yr 5-15.

Current and Mean Annual Increments

The annual measurements of study plots through yr 11 provide first-published data for early annual growth patterns for loblolly pine plantations. These annual patterns along with yr 1 l-15 periodic annual increments (PAIs) are compared with growing season (gs) rainfall patterns in Figure 4. During this period, annual gs rainfall varied by ±30–40% of the mean

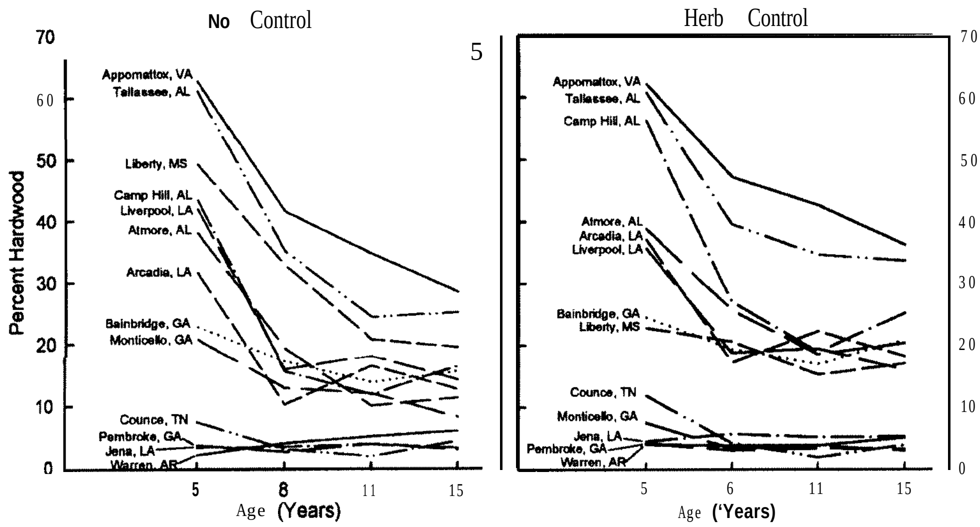

Figure 3. Percent hardwood basal area of total stand basal area over time for No Controls and Herb Controls by site.

for successive years, which permits examination of these fluctuations relative to incremental growth.

Current annual increment (CAI) for height on W+H Controls peaked in yr 4 or 5 at an average of 4.1 ft/yr for Low Hardwoods, 5.3 ft/yr for High Hardwoods, and 5.7 ft/yr for High Shrubs (Figure4). Actual peak height growth by locations for W+H Controls occurred in yr 4-8, with the greatest at Bainbridge in yr 4 at 6.5 ft/yr. In general, W+H and Herb Controls approached maximum height CAIs by yr 4 after increasing rates from yr 2-3. Herb Controls peaked at a height comparable to W+H Controls for Low Hardwoods and about 1 ft less for High Hardwoods and High Shrubs. Herb Control peaks for individual sites occurred from yr 4–9, being later for the highest hardwood sites. On average, Woody Controls and No Controls peaked in yr 6-8 across all sites, with the greatest for Woody Controls at Pembroke, GA in yr 8 at 5.9 A and for No Control at Bainbridge in yr 9 at 5.4 ft. It is evident that the average potential period of maximum height growth for all treatments occurred in yr 4-9. By yr 10-l 1, height growth had become similar for all treatments and appears to have started declines from peak CAIs, while gs rainfall during this period was above or near average.

Below-average gs rainfall in yr 3–5, 7, and 10 is evident as lower incremental height growth for most sites and treatments (Figure 4). Increased growth is also evident with the higher than average rainfall of intervening years, with no apparent lag year with slower growth following low rainfall years. Year 3-5 had below average gs rainfall and yet had increasing growth rates that indicates an early period of accelerated juvenile height growth.

CAIs for pine BA culminated on average 2 yr later than CAIs for height (Figure 4). Pine BA CAIs on average peaked in yr 6 for W+H Controls at 23 ft^2/ac/yr for Low Hardwoods, 24 ft^2/ac/yr for High Hardwoods, and 19 ft^2/ac/yr for High Shrubs. This culmination coincided with the yr 6 above-average gs rainfall. The other treatments culminated most often in yr 6, but varied on a site basis from yr 5-l 1. After yr 8, Woody Control averages tended to equal or slightly exceed W+H Control BA increments. BA increments for W+H and Herb Controls declined after yr 6, while other treatments increased or remained constant to decline after yr 8 or 9. By yr 15, BA periodic annual increments (PAIs for yr 1 l-15) on all sites were in a confined range of 6–1 1 ft^2/ac/yr. Below average gs rainfall in yr 7 and 10 coincide with suppressed BA growth at yr 10 on Low Hardwood BA sites and both yr 7 and 10 on High Shrub sites, and being less evident on High Hardwood sites that hadgreater average rainfall than the other categories.

Volume CAI culmination occurred on average in yr 11 for W+H Controls on Low Hardwoods, withmerchantablevolume ranging from 415-529 ft^3/ac/yr (5.1-6.6 cd/ac/yr); yr 7-l 1 on High Hardwoods, ranging from 365487 ft^3/ac/yr (4.6-6.1 cd/ac/yr); and yr 8-9 for High Shrubs, ranging from 368446 ft^3/ac/yr (4.6–5.6 cd/ac/yr). Culmination of CAIs on W+H Controls on individual locations occurred from yr 6-l 1 and CAIs remained fairly constant over this period, only decreasing during dry years. Volume CAIs accelerated most rapidly during the juvenile growth phase in the first 8 yr for W+H Controls and during the first 1 1 yr for the other treatments. The largest volume gain on W+H Controls occurred on average in yr 6 across all three woody competition categories, whereas other treatments had more steady increments during this period (owing that Herb Control on Low Hardwoods is similar to W+H Control). Thus, the culmination of CAI was more a multiyear period, not a single year. During yr 12-15 (with PAIs shown in Figure 4), it is assumed that maximum or near maximum growth increment had been reached and CAI growth had leveled or possibly declined. Average gs rainfalls from yr 12-l 5 were very close to overall averages (Figure 4, dash line at 36 in. gs rainfall).

On Low Hardwood BA locations, all treatments had similar yr 15 PAIs of about 340 ft^3/ac/yr (4.2 cd/ac/yr). On High Hardwood locations, W+H Controls were growing on average 55 ft^3/ac/yr more wood than Woody Controls at yr 11, but were essentially equal by yr 15. On these same sites, Herb Controls were nearly equal to No Controls for both yr 11 and 15. On High Shrub locations, W+H Controls and Woody

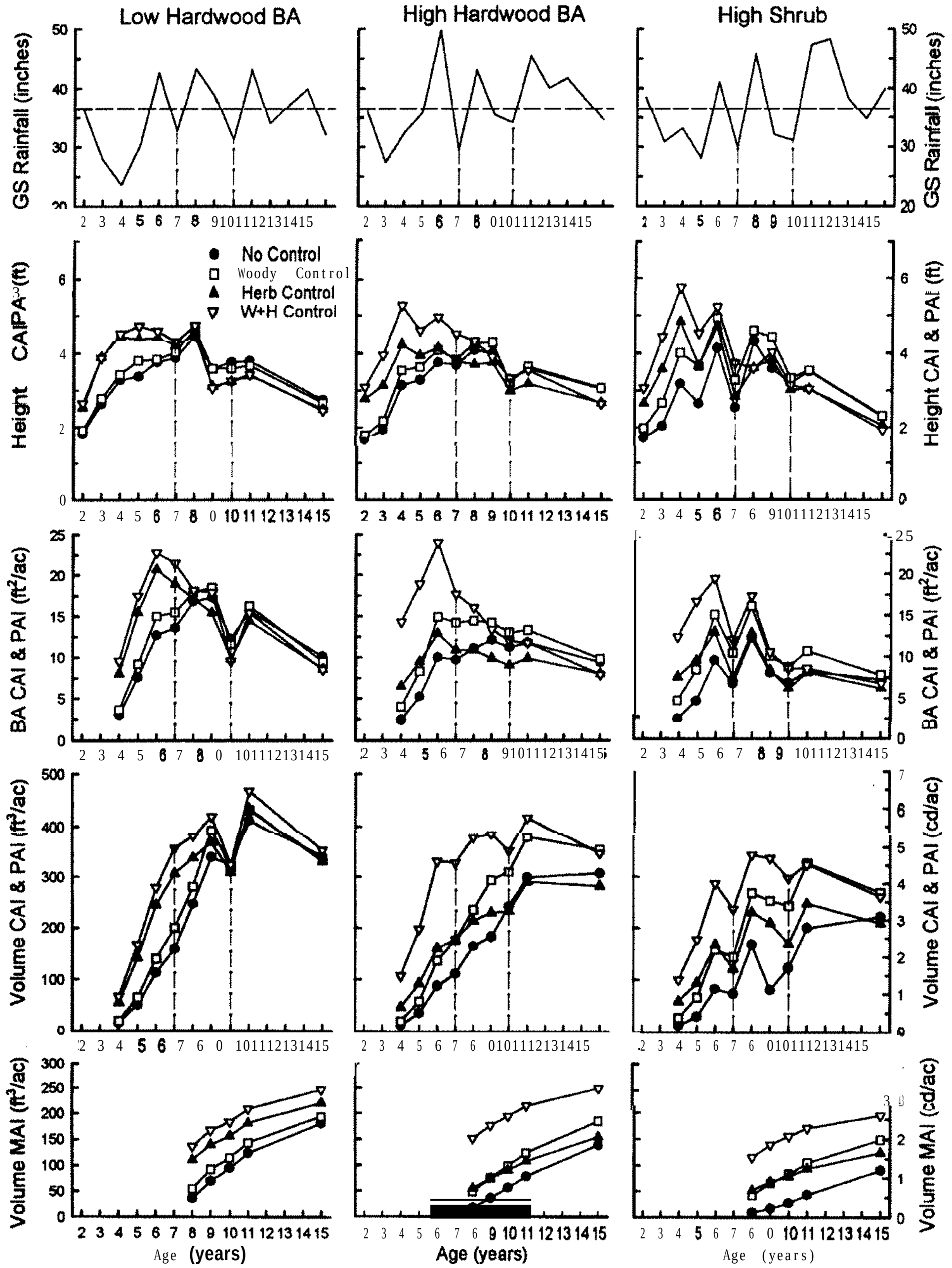

Figure 4. Growing season (gs) rainfall from March through October (dash line is 15 yr overall mean), current and periodic annual increments (CAI yr 2-I 1 and PAI yr 1 I-15) for height, basal area and volume, andvolumemean annual increment (MAI, yr 2–8 are volume index and yr 9–15 are merchantable volume) by woody competition category and vegetation control treatment.

Controls were nearly equal for yr 11 (324 vs. 327 ft^3/ac/yr, respectively) and yr 15 (261 vs. 269 ft^3/ac/yr, respectively). And on High Shrub sites, average PAIs were equal for Herb Controls and No Controls (208 vs. 221 ft^3/ac/yr, respectively). On High Hardwoods and High Shrubs, the growth increment for Woody Control exceeded that for Herb Control starting in yr 7 or 8.

Mean annual increments (MAIs) in yr 1.5 for all the sites ranged (with averages) as follows: No Control, 75-198 ft^3/ac/yr (average = 145 ft^3/ac/yr); Woody Control, 139-232 ft^3/ac/yr (average = 182 ft^3/ac/yr); Herb Control, 75–255 ft^3/ac/yr (average = 170 ft^3/ac/yr); and W+H Control, 157-294 ft^3/ac/yr (average = 240 ft^3/ac/yr). MAIs continue to increase, not appearing to have reached an asymptote by yr 15 for any treatment and location (Figure 4).

Average MAIs for W+H Controls in yr 1.5 on the Low and High Hardwood sites were similar at 247 ft^3/ac/yr (3.1 cd/ac/yr) and 250 ft^3/ac/yr (3. 1 cd/ac/yr), respectively, with the High Shrub average being 195 ft^3/ac/yr (2.4 cd/ac/yr). The largest MA1 for a single location with W+H Control occurred at Liberty, MS at 294 ft^3/ac/yr (3.7 cd/ac/yr). Woody Control MAIs were also similar with Low and High Hardwoods sites, being 194 ft^3/ac/yr (2.4 cd/ac/yr) and 185 ft^3/ac/yr (2.3 cd/ac/yr), respectively, with High Shrubs being 149 ft^3/ac/yr (1.9 cd/ac/yr). MAIs on Herb Controls varied widely by woody competition category and averaged 221 ft^3/ac/yr (2.8 cd/ac/yr) for Low Hardwoods, 155 ft^3/ac/yr (1.9 cd/ac/yr) for High Hardwoods, and 124 ft^3/ac/yr (1.5 cd/ac/yr) for High Shrubs. These data indicate the herbaceous competition pressure (i.e., on Woody Controls) was more similar, compared to woody plant competition that varied considerably by the three categories on the Herb Control treatments. With less than half the productivity of the W+H Controls, the No Controls on High Shrub sites averaged 9 1 ft^3/ac/yr (1.1 cd/ac/yr). The No Controls on Low and High Hardwood BA sites were 181 ft^3/ac/yr (2.3 cd/ac/yr) and 139 ft^3/ac/yr (1.7 cd/ac/yr), respectively.

Relationships Between Woody Competition and Pine Growth

Combining and analyzing 15 yr data from all sites for No Controls and separately for Herb Controls identified strong linear relationships between measures of woody competition and merchantable pine volume as well as relative pine volume loss scaled to the W+H Controls (Table 2). Woody competition measures examined were hardwood BA, percent hardwood BA to total stand BA, and the combined measure for hardwoods and shrubs, "sum of woody heights" (i.e., sum of stem heights for hardwoods plus sum of rootstock heights for shrubs).

Omission of the two High Shrub sites improved the correlation coefficients between hardwood competition and pine response, due to the abundance of shrubs on these sites not accounted for in a hardwood model (Table 2). As might be expected, correlation coefficients were slightly greater for those relationships on Herb Controls where only woody competition was dominant as compared to those on No Controls where both woody and herbaceous competition were interacting. Scaling pine volumes to loss values using the W+H Controls as well as scaling hardwood BA to a percent of total stand BA improved the strength of the corresponding linear relationships. In general, relationships had corresponding greater R-values (and probabilities) between all woody measures and relative pine volumes loss, versus those with actual pine volume. Thus, relative measures of pine volume loss and hardwood BA were examined further and the results are presented in Figures 5 and 6.

All linear relationships between merchantable volume loss (both actual and percent) and the three woody competition measures were significant, while the amount of explained variation ranged from 73-89% (R^2) when hardwoods variables were regressed and 45–69% when hardwoods and shrubs were combined (Figures 5 and 6). Sum of woody heights gave the weakest relationships but had the advantage of including all sites and both hardwoods and shrubs. It is apparent from the graphs of Herb Control that among those sites with high hardwoods there were four sites with lower productivity and four sites with higher productivity, indicating unexplained variation attributable to site.

Y-intercepts of No Controls (the point with zero hardwoods and maximum herbaceous competition) yielded estimates of the average 15 yr loss in merchantable volume attributed to herbaceous competition and ranged from 712-768 ft^3/ac (8.9–9.6 cd/ac) or a loss of 15-19% of potential productivity. For Herb Controls, none of the y-intercepts were significant] y different from zero (SAS t-statistic), indicating the absence of any unexplained influences.

When slopes for No and Herb Controls were analyzed for homogeneity (i.e., to test whether they were equal), the slopes of the six pairs of equations were determined not to be statistically different at the 0.05 level (analyses not shown). Thus, it could be summarized that hardwoods and shrubs reduced pine volume by the same amount whether growing with or without the early herbaceous component. However, the consistently greater slopes with Herb Controls as compared to No Controls, although only slightly greater, would suggest more competitive influences of the released hardwoods grown without early herbaceous competition. These equations indicate that when herbaceous competition is present on No Controls, every square foot of hardwood BA subtracted about 37 ft^3/ac or 1.1% of the potential merchantable volume. On Herb Controls, every square foot of hardwood BA without herb competition subtracted 43 ft^3/ac or a 1.2% loss in merchantable volume. Each percentage of hardwood BA subtracted 47 ft^3/ac (1.4%) of pine volume on No Controls and 48 ft^3/ac (1.6%) on Herb Controls. With sum of woody heights, 1,000 ft in heights of hardwoods and shrubs subtracted 18 ft^3/ac (0.7%) on No Controls and 32 ft^3/ac (0.9%) on Herb Controls.

Discussion

Fifteen yr of data from the network of COMProject study locations-with detailed pine, associated plant, and site measures-provide unique insights into pine productivity, stand dynamics, and competition-pine relationships for numerous sites and competition categories across the region. Site index calculations indicate these sites are medium to high in pine productivity, with about half the sites being nutrient deficient in P and N according to yr 2 and yr 6 foliar analyses (Zutteret al. 1999). Thus, these findings apply to nonfertilized plantations within the fertility range expected for common soil series.

In this study, loblolly pines in well-stocked stands increased their dominance in proportion to hardwoods up to midrotation. The proportion of hardwood BA to total stand BA generally declined from yr 5-15 when stands had over 50% hardwood BA at age 5; declined from yr 5-8 and then remained constant to yr 15 when stands had 1 0–50% hardwood BA at age 5; or remained essentially constant for stands that had less than 10% hardwood BA at age 5. These trends differ from those reported as constant proportions of hardwoods to total stand BA for a northern Alabama plantation with hardwoods in the main canopy (Glover and Zutter 1993) and for mechanically site-prepared plantations in mid-South states (Knowe 1992). Our region-wide data add substantially to the limited observations for Georgia and Virginia that also indicated a general decreasing proportion of hardwood-to-total BA (Zahner and Myers 1984, Smith et al. 1989).

Pine survival and mortality from yr 2 (after thinning of double plantings) through yr 15 was not generally related to

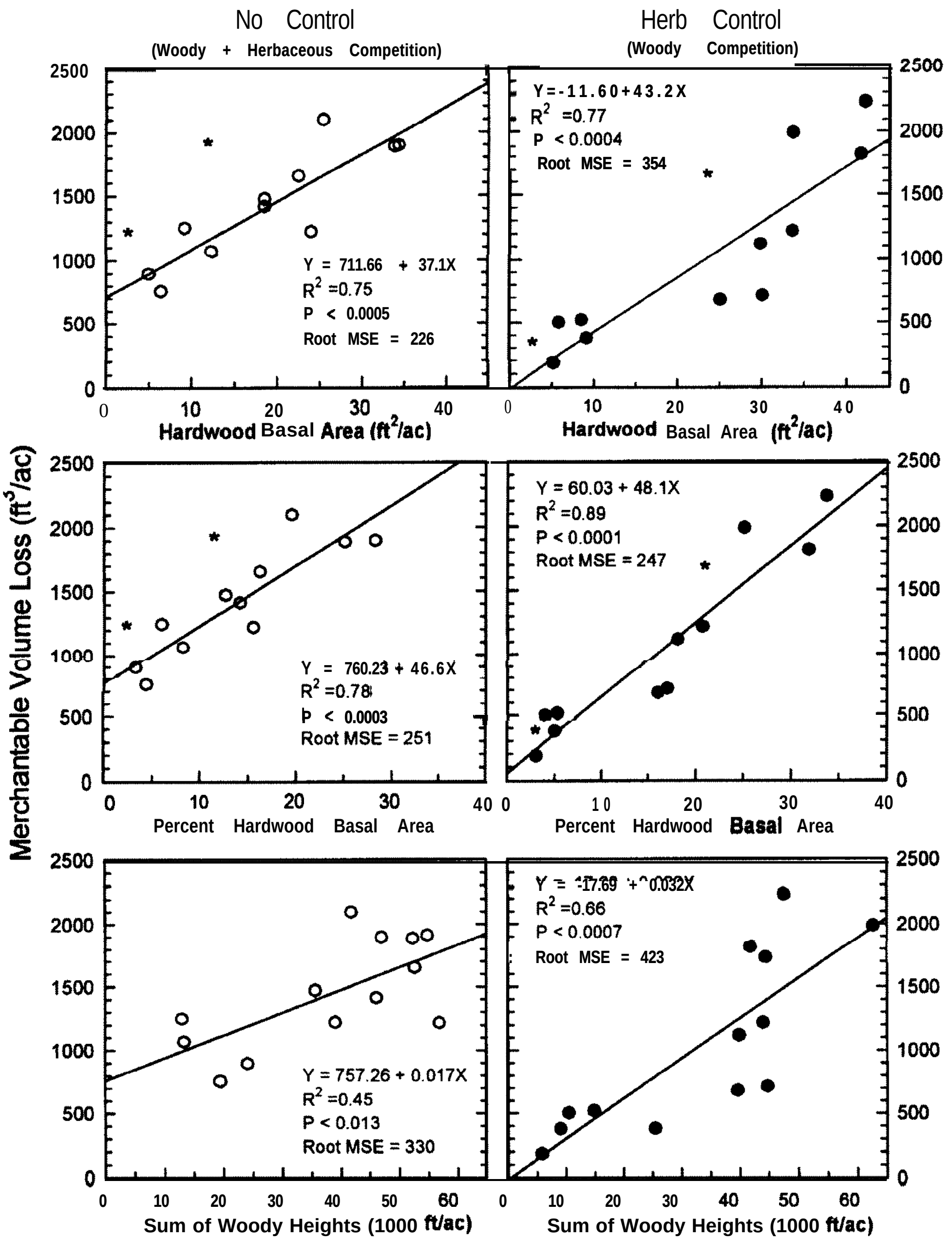

Figure 5. Linear regressions for merchantable volume loss of loblolly pine relative to three different measures of woody competition for No Control and Herb Control across locations at yr 15. High Shrub sites not included in top four regressions, but their data denoted by asterisks.

early vegetation control treatments. The ensuing competition coupled with early dry years did not consistently alter pine density. However, survival was reduced significantly on 2 sites where early competition was severe due to overtopping row-crop weeds and dense hardwoods. Others have reported: a similar absence of increased survival of loblolly pine with herbaceous control (Michael 1985, Bacon and Zedaker 1987, Zutter et al. 1987a, McKee and Wilhite 1988, Glover et al. 1989, Miller 1990, Haywood 1994, Jokela et al. 2000); increased survival with herbaceous control (Haywood and Tiarks 1990, Yeiser and Williams 1996); decreased survival apparently due to herbicide damage (Fitzgerald and Fortson 1979, Allen and Lien 1998); and site-dependent survival influences (Latter et al. 1993, South and Barnett 1986). The extra care used to plant our sites (only two operationally planted), the care in herbicide applications to avoid seedling damage, and study sites that were not marginal for loblolly pine probably assured the survival.

Differences in pine growth between No Controls and W+H Controls are comparable to those reported for other studies within the region that included similar treatments. Borders and Bailey (2001) reported on multiple sites in Georgia (including high shrub sites) for ages 10–12 yr and found gains of 1,000–1,600 ft^3/ac for complete controls vs. no controls (without fertilization). In the current study, gains in yr 11 were 950–1,400 ft^3/ac as the averages by woody competition

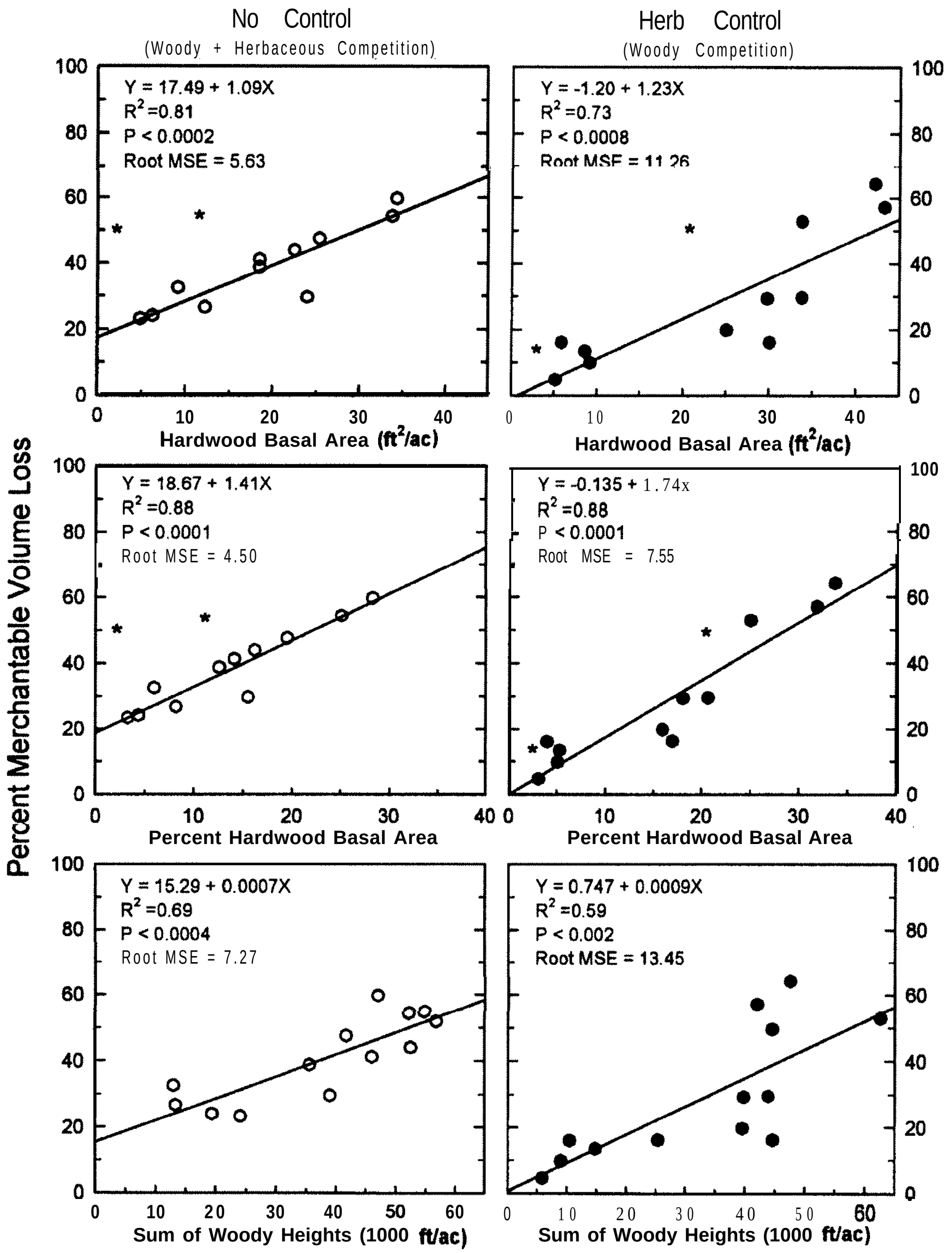

Figure 6. Linear regressions for percent reduction in merchantable volume of loblolly pine relative to three different measures of woody competition for No Control and Herb Control across locations at yr 15. High Shrub sites not included in top four regressions, but their data denoted by asterisks.

categories. These gains are greater than the 600 ft^3/ac reported in yr 11 by Haywood and Tiarks (1990) for a phosphorus-deficient site in Louisiana, where woody control did not result in as long a period of response. The gains are much greater than those reported by Allen and Lein (1998) for 12 study sites located throughout the loblolly pine region. In their study, average 14 yr responses to 2 yr of weed control ranged from only 321 ft^3/ac on poorly drained sites to 28 ft^3/ac on well-drained sites. As the authors note, some of this lower response was probably the result of herbicide damage.

In another multisite study of loblolly pine plantations, Jokela et al. (2000) found at yr 8 on high shrub sites in Florida, southern Mississippi, and Georgia that average volume gains with 1 yr of herbaceous control (and unspecified woody competition) ranged from 69-l 10 ft^3/ac by soil group (and increased to 236-7 17 ft^3/ac with fertilizer additions). Average volume gain for the High Shrub sites of the current study with similar competition and 3–4 yr of control was 325 ft^3/ac at yr 8. These findings indicate that responses to herbaceous weed control can be limited by duration of control, the amounts of hardwoods remaining, and/or nutrient deficiencies.

Cain (1999) reported on a study using the COMProject design with natural regeneration of loblolly and shortleaf pine (*Pinus echinata* Mill.) in southeastern Arkansas, which was thinned to 500 trees/ac at age 5. When comparing yr 11 results between this Crossett AR location and the nearby Warren, AR planted location (similar site indices), Woody Control gained 372 ft^3/ac (natural) vs. 45 1 ft^3/ac (planted), Herb Control gained 873 ft^3/ac vs. 905 ft^3/ac, and W+H Control gained 1490 ft^3/ac vs. 1183 ft^3/ac, respectively. Both locations responded in a similar manner to woody and herbaceous control, but the response to total competition control was greater at Crossett. The Warren site has a distinct plow-pan and was most likely cultivated for a longer period than Crossett, which has been maintained in forest cover since the early 1900s.

Volume CAIs (and PAIs for yr 1 I-15) were greater when both competition components were controlled than when only one component was controlled until yr 1 O-l 5. Early control of either woody or herbaceous components accelerated volume growth compared to No Control. Accelerated early growth during the first 6 yr with Herb Control was comparable with W+H Control on sites with low woody competition, while Woody Control never approached the early growth gains observed for W+H Control on any location. Allen and Lein (1998) also described (no data shown) an advancement of the culmination of volume CAIs with intensive treatments, including vegetation control on several sites across the Coastal Plain. They also found the volume culmination on intensively treated sites to be between yr 6-10, which was 4-6 yr before culmination on plots without treatment. Cain (1978) also reported culmination of biennial PAIs in yr 6-8 for loblolly pine in Louisiana, which did not vary among mechanical site preparation or check treatments. In the current study we see volume culmination somewhere between yr S-15.

CAI values mirrored gs rainfall, but only after their culmination. During the accelerated juvenile growth phase through yr 8, rainfall appeared to be less influential on growth increment, even with a succession of dry-wet-dry year cycles (i.e., yr 6–8) (Figure 4). This wouldsuggestthat theaccelerated juvenilegrowth is more physiologically than environmentally determined. But as growth increments slowed, and pronounced general dry yr 10, and yr 9 and 10 for High Hardwoods and High Shrubs occurred, major declines in growth for all treatments andcategories were apparent with decreased rainfall. Declines were most pronounced with the faster growing treatments, but less so on the High Shrub locations where growth on all treatments declined measurably with two dry years. CAIs for pine height, BA, and volume were decreased by about 5-27% when gs rainfall (March through October) was less than 36 in. The dramatic resumption of growth in yr 1 1-ageneral "wet" year-was alsoevident for all treatments, indicating there was no perceptible lag year after a dry year. It is apparent that the vagaries ofyear-to-year rainfall result in variable growth increments that do not conform to smooth-line models, but resilient growth rates in wet years after dry years resume growth at rates that would be approximated by smooth-line models.

MAIs for all treatments at all locations were seemingly still increasing at yr 15. This understanding should aid the interpretation of early MAIs recently reported for loblolly pine grown both regionally and internationally. Borders and Bailey (2001) reported loblolly MAIs for yr 10–12 at five locations in Georgia with roller drum site preparation as 103-247 ft^3/ac and with herbaceous control as 221-340 ft^3/ac, compared to our lower yr 11 results from Georgia at 37-147 ft^3/ac and 133-246 ft^3/ac, respectively. In the same report, Borders and Bailey also cited international results for loblolly plantations grown with intensive management having MAIs of 37 l-523 ft^3/ac (years various, 8-22 yr), which are greater than any findings reported here and may be due to inherent site productivity differences. They found that early fertilization in Georgia had sizable but mixed results, and the international values were all with fertilization,

Fusiform rust infections and mortality from infections in areas of high incidence (Alabama and Georgia) were 9916% greaterwith intensive herbaceous control on all sites and were 6-l 1% greater with woody plant control on half the sites. These increases were generally additive in nature when both treatments were used in high incident locations. Glover and Lauer (1998) reported **that** 5 of 7 loblolly pine plantations in Alabama at ages 12–15 had significant increases in stem gall incidence of 540% after 2 yr of herbaceous plant control. Zutter et al. (1987b) reported on some ofthese same locations at age 5 and determined that stem infected trees were smaller in dbh and height than noninfected cohorts. Kane (1982) found only l of 7 study sites in six midsouth states had significantly more stem galls following 2 yr of herbaceous weed control. The current dataalong with theseothermultisite reports would indicate that the incidence inmainstem fusiform galls could be significantly increased with both herbaceous and wood plant control in high infection areas, especially when highly susceptible genotypes are planted. The influence on growth deserves closer study.

Linear regressions adequately described the relationship between pine merchantable productivity and hardwood presence at age 15. There was no evidence of thresholds in these relationships in the range ofcompetition intensity studied contrary to a general model for crop-competition described by Radosevich et al. (1997, p. 202-204). To achieve significant linear relationships for hardwoods BA and pine growth, the High Shrub sites had to be omitted. Only by expressing the sum of hardwood and shrub abundance (by summing their heights) were significant relationships achieved for all sites and these were less significant than the former.

Conclusions

Pine productivity remained altered in yr 15 by the intensive vegetation control treatments in the first 3-5 yr. Early intensive control of both woody and herbaceous competition increased 15 yr volumes by 23–121%, with gainsincreasingas hardwoods and shrubs increased in the No Controls. Merchantablevolume yields after 15 yr with early near-complete competition control for the 13 sites were 2,350–4,415 ft^3/ac. Early woody control treatments increased merchantable pine volume on 11 sites by 344-l,5 15 ft^3/ac, + 14–118%, or an average increase of 9 15 ft^3/ac for these sites. Gains from early herbaceous treatments were substantial but somewhat less significant on 10 sites by an additional 40991,159 ft^3/ac, + 17–50%, and averaged 707 ft^3/ac for these sites.

Responses to woody and herb control were generally additive, except that woody control treatments on some low hardwood locations did not result in significant pine growth. Conversely, when herbaceous control treatments were applied to locations with high hardwood levels (greater than about 5 ft^2/ac BA at yr 5), productivity was equal to or less than untreated plots owing to enhanced woody competition. Generally, gains were greatest on high hardwood BA and high shrub sites with woody control, while gains on low hardwood sites were greatest with herbaceous control.

Linear regressions adequately described the relationship between pine merchantable productivity and hardwood co-occupation at age 15. Contrary to purposed universal models for crop competition, there was no evidence of thresholds (nonlinear portions) in these relationships in the range of competition intensity studied. These regressions showed that merchantable pine volume was decreased by about 1.1% for each ft^2/ac of hardwood BA present at yr 15 when herbs were not controlled or about 1.2% when herbs were controlled. Besides losses in volume due to competition, Carpenter (1999) analyzed data for individual pine trees from each of these sites through age 11 and found that increased component control decreased standard deviations and coefficients of variation of pines to yield more uniform stands.

Pine survival and stocking were not consistently altered by early control treatments. Woody control did not increase survival even on sites with early dense hardwood competition, which are some of the few reported data on woody competition effects on pine survival for the region. Considering these data and others' findings, it is concluded that pine survival is only increased when appropriate herbicides for herbaceous plant control reduce severe competition and result in minor seedling damage, on drier sites and/or during drier establishment years, more frequently encountered in the western part of the southeast region.

It is evident from growth curves for pine dimensions and volume through 15 yr that early growth in yr 1-4 was not a good predictor of later growth after yr 6 onward when abundant hardwoods and/or shrubs were present. Early increases in pine growth from herbaceous control were not sustained due to the later growth subtractions by developing woody competition. Insights from these longer term data should temper interpretations from research reports on "early results," which are the majority. Early growth increases from herbaceous control are sustained only in the absence of woody competitors.

Contrary to common presumptions and commonly used growth and yield tables (e.g., USDA 1976), pine BA on plots with early complete competition control had reached 122-184 ft^2/ac by yr 15, exceeding levels in these older tables. Thus, concepts of carrying capacity for sites need to evolve as intensive forestry creates levels of pine BA not previously recorded. Also, contrary to some general assumptions used in current growth and yield models that were based on limited data, the hardwood proportion of stand BA decreased from yr 5-15, when yr 5 BA exceeded about 10 ft^2. This indicates that pines in well-stocked plantations are more competitive than midstory and understory hardwoods and continue to increase in relative proportion through age 15.

Maximum annual productivity achieved by early control of both woody and herbaceous competition resulted in a culmination of volume CAI in yr 8-11 at 250-470 ft^3/ac/yr (3-6 cd/ac/yr), which appears to decline slowly afterward. Increased rates of juvenile growth, not changes in patterns of growth, characterized the response in CAI after competition control. Growing season rainfall (March-October) of less than about 36 in. negatively influenced CAIs of height, BA, and volume by 5–27%. Volume MAIs have not culminated on any treatment on any of the 13 locations by yr 15 and ranged from 157-294 ft^3/ac/yr (2-3.6 cd/ac/yr) with complete early competition control.

In areas of high incidence, mainstem fusiform rust infections and mortality related to infection increased with both early woody and herbaceous control. Increased infection was more commonly associated with herbaceous control than woody control and increases were additive when both treatments were used.

This regional study is scheduled to continue to yr 25, which will permit testing whether site index values are influenced by early vegetation management treatments. Other ongoing sampling and analyses will examine vegetation management treatment influences on pine wood properties, soil carbon and nitrogen sequestration, and further track pine foliar nutrients (Zutter et al. 1999) as well as public stand preferences (Gan and Miller 2001).

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