A Comparison of Planted Loblolly Pine (*Pinus taeda*) Growth in Areas Receiving Different Levels of Establishment Regime Intensity

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ABSTRACT. Management intensity of southeastern US pine (*Pinus spp.*) plantations has increased during past decades, emphasizing timber production. Managers need more information about tree growth responses to different establishment intensities to successfully meet their economic and ecological objectives. We established a comparison of

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five loblolly pine (*P. taeda*) plantation establishment regimes in the Mississippi Lower Coastal Plain (LCP, $n = 4$), using a gradient of mechanical and chemical site preparation and herbaceous weed control intensities. Treatments varied from "low intensity" to "high intensity" and were expected to produce a gradient in vegetative and pine growth response. We monitored herbaceous and woody ground cover, woody stem density, pine survival, and pine growth during years one and two post-treatment (2002 and 2003). Herbaceous cover, woody cover, and woody stem density decreased as treatment intensity increased. Pine survival was less on treatment 5 and decreased slightly on all treatments during 2003. Pine height and diameter increased as treatment intensity increased, except for the treatment with no mechanical preparation, indicating the importance of subsoiling and bedding in the LCP. After two growing seasons, a combination of mechanical and chemical site preparation followed by one or two years of broadcast herbaceous weed control maximized pine growth.

KEYWORDS. Growth, herbaceous weed control, loblolly pine, pine plantation, *Pinus taeda*, site preparation, subsoiling, tree diameter, tree height

INTRODUCTION

Forest management in the Southern US has intensified over the past several decades as evidenced by increased use of genetically improved planting stock, increased fertilizer and herbicide applications (Siry, 2002), financial considerations, and concerns about future timber supplies (Sedjo and Botkin, 1997). Rather than a single herbicide application at stand initiation, future establishment regimes will likely include herbicide tank mixes prior to planting to eliminate woody competition, followed by one or two years of herbaceous release treatments during the first and second growing seasons after planting. Additionally, as production rates increase, stand rotations likely will become shorter (Borders and Bailey, 1997).

Numerous studies have documented effects of herbaceous and woody (i.e., hardwood) control on pine growth. Herbaceous vegetation is the primary pine competitor early in stand development (Tiarks and Haywood, 1986; Haywood and Tiarks, 1990; Cain, 1991), but control of herbaceous and woody components allows even greater pine growth (Pienaar et al., 1983; Bacon and Zedaker, 1987; Miller et al., 1995). Additionally, the early pine growth advantage afforded by competition control often persists into later stand development stages (Pienaar *et al.*, 1983; Glover and Zutter, 1993).

Numerous site preparation methodologies are available to managers including mechanical and/or chemical treatments and may result in varying levels of competition control efficacy (Shiver and Martin, 2002). Mechanical site preparation such as subsoiling improves pine survival and growth by increasing soil volume available to roots, thus increasing water and nutrient availability (Allen and Lein, 1998). Bedding enhances survival and growth by consolidating topsoil and improving aeration in poorly drained areas (Smith et al., 1997). The combination of mechanical and chemical site preparation can be a more effective means of controlling competition than a single method used alone (Lauer et al., 1998), thus shortening the time required to meet silvicultural goals of site preparation.

Forest product companies are concerned with the operational establishment of pine plantations. However, much of the published research concerning site preparation effectiveness on pine growth was not approached from an operational standpoint (e.g., experimental plots < 1 ha in size, treatments involving complete vegetation control for > 2 years) and the results, although providing valuable information, have not addressed industry operational needs.

The objectives of our research were to establish a gradient of operational, loblolly pine (*Pinus taeda*) plantation establishment intensities and quantify control of vegetative competition and its effect on pine growth. We hypothesized that vegetative control and pine growth response would be altered by treatment intensity. We predicted that the response of competing vegetation would be associated negatively and that pine growth would be associated positively with treatment intensity. The results of this research are a subset of a larger project investigating effects of intensive pine plantation management on wildlife habitat quality in the Mississippi Lower Coastal Plain. Quantifying relationships between management intensity, pine growth, and wildlife habitat quality will allow resource managers to evaluate trade-offs between timber production and wildlife habitat provision, and ultimately make better informed land management decisions.

STUDY AREAS AND METHODS

The effects of five levels of pine plantation establishment intensity on vegetative control and pine growth were monitored on four tracts of land owned by forest product companies in George, Lamar, and Perry counties in southern Mississippi. Vegetation on all stands was typical of the Mississippi Lower Coastal Plain (LCP), a low fertility, acidic-soils physiographic region referred to as the "piney woods" where longleaf pine (*P. palustris*) historically occurred (Pettry, 1977). Stands were harvested during summer 2000-winter 2001, averaged 66 ha in size, and each was uniformly influenced by topography and drainages.

Soil associations were fairly consistent among the study sites. The McLaurin-Heidel-Prentiss association was common to two stands and was composed of gently sloping, moderately well-drained, sandy and loamy soils. The McLaurin-Savannah-Susquehenna association, comprising somewhat poorly drained, nearly level upland soils, occurred on one stand. The Prentiss-Rossella-Benndale as associated occured on two stands and was characterisitics by loamy fine and sandy loam soils.

Establishment regimes (i.e., treatments) were selected to represent a range of operational intensities in timber industry stand establishment techniques. The regimes were expected to stimulate the development of distinct communities that represented a gradient in vegetation management intensity and potential pine growth response. Treatments were arranged in a randomized complete block design where each of the five treatments was assigned randomly to a $P \geq$ 8-ha area within each of four stands. Management intensity, and thus expected pine growth response, increased from "low" for treatment 1 to "high" for treatment 5.

The regimes consisted of different combinations of mechanical and chemical site preparation and banded and broadcast herbaceous weed control. Treatment 1 consisted of mechanical site preparation using a combination plow pulled behind a bulldozer with a V-blade attached to the front to clear debris. The plow subsoiled, disked, and bedded in a single pass. A banded herbaceous control in year one was applied using 0.9 kg/ha of Oustar® Treatment 2 consisted of chemical site preparation using a mixture of 2.4 L/ha Chopper EC®, 5.3 L/ha Accord®AE, 5.3 L/ha Garlon 4, and 1% volume to volume ratio of Timberland 90 surfactant in a total spray solution of 93.6 L/ha. A banded herbaceous control was applied in year one using 0.9 kg/ha of Oustar®. No mechanical site preparation occurred in Treatment 2. Treatment 3 consisted of chemical site preparation (same as treatment 2) followed by mechanical site preparation (same as treatment 1). A banded herbaceous control in year one was applied using 0.9 kg/ha of Oustar®. Treatment 4 consisted of chemical (same as treatment 2) followed by mechanical (same as treatment 1) site preparation. A broadcast herbaceous control in year one was applied using 0.9 kg/ha of Oustar®. Treatment 5 consisted of chemical (same as treatment 2) followed by mechanical (same as treatment 1) site preparation. A broadcast herbaceous control in years one and two was applied using 0.9 kg/ha of Oustar®.

All chemical site preparation treatments were applied during July-August 2001 and all mechanical site preparation was completed during September-December 2001. The stands were not burned. Year one herbaceous control applications were completed during March-April 2002 and year two herbaceous treatments were completed during March-May 2003.

Stands were planted during December 2001-January 2002. Each timber industry cooperator planted their own genetically improved, loblolly pine seedlings. Seedlings were planted with 3.0 m between rows and 2.1 m between trees within a row, totaling 1,551 trees/ha. All stands were scheduled for machine planting to facilitate banding applications. However, two stands were hand planted due to greater debris loads remaining post-harvest. Banded herbaceous control was applied by hand on these two sites.

Additional management activities were standardized across all treatment plots and blocks. Banded herbaceous control treatments were applied via tractor with a band width of 1.5 m, and broadcast herbicide applications were applied aerially via helicopter. A broadcast fertilizer application of DAP at 280 kg/ha was aerially applied to all treatments during April 2002.

We evaluated woody (i.e., hardwood) stem density pre-treatment (July 2001) and during years one and two post-treatment (June 2002 and June 2003). During 2001, density estimates of woody stems (∃0.5 m tall were obtained along five, randomly located 30- × 2-m belted- transects within each treatment. During 2002 and 2003, estimates of woody stems (0.5 m tall within each treatment were obtained using 40, randomly located 1-m^2 circular plots. Because the size of woody stems was reduced post-treatment, we changed sampling methodology to increase sample size and ensure sufficient sampling within experimental units.

We quantified vegetative communities during June 2002 and June 2003, years one and two post-treatment. We recorded percentage ground cover of understory woody and herbaceous species using a modification of Canfield's (1941) line-intercept method within each treatment along 10, randomly located 30-m transects. A 30-m buffer zone at treatment boundaries was excluded from sampling. We identified plants by species and then categorized by forage type (i.e., herbaceous or woody).

We measured pine growth response on each treatment plot to compare the effectiveness and competition control benefits of site preparation and herbaceous weed control treatments. One pine measurement plot (0.04-ha, 7 rows of 10 trees) was established within each treatment area. We measured height (m) and ground level diameter (mm) of seedlings during June 2002, June 2003, and January 2004. Survival estimates were based on the 2002 and 2003 data whereas growth estimates were based on the 2002 and 2004 data.

We used a repeated-measures, mixed model analysis of variance to test for main effects of year and treatment and year × treatment interaction for woody stem density, woody canopy coverage, herbaceous canopy coverage, and pine survival, height, and diameter. We compared means among treatments (n = 5) and between years (n = 2) using SAS Proc MIXED (SAS Institute, 2000). We treated stands (i.e., blocks, n = 4) as the random effect, years as the repeated effect, treatment × stand as the subject, and we chose a first order autoregressive covariance structure for the models because there was one time interval between sampling periods (Littell et al., 1996). We considered differences significant if $P < 0.05$. We compared means using Fisher's least significant difference with the LSMEANS PDIFF option (Littell et al., 1996). We tested normality and equal variance assumptions prior to each analysis and we square-root transformed variables with non-equal variances (Zar, 1999). For ease of data interpretation, actual means are presented although we conducted analyses on transformed data.

RESULTS

Site preparation reduced woody stem density (Table 1). The 3 dominant species detected prior to treatment were common persimmon (*Diospyros virginiana*), wax myrtle (*Myrica cerifera*), and yaupon (*Ilex vomitoria*). There were no pre-existing differences in density of individual species and the total of all species among treatments ($F_{4,15}$ = 0.13, P = 0.974). The site preparation treatments controlled all woody

TABLE 1. Woody stem density (trees/ha \$0.5 m tall) for 5 pine plantation management regimes varying from low (1) to high (5) intensity at pre-treatment (July 2001) and and at years 1 and 2 post-treatment (June 2002 and June 2003) in the Mississippi Lower Coastal Plain[a].

	Treatment												
	1[b]		2[c]		3		4		5		P-value[d]		
Species	*x*	SE	*x*	SE	*x*	SE	*x*	SE	*x*	SE	Yr	Trt[e]	Yr*trt
Pre-trt (2001)													
Common persimmon	675.0	149.8	283.3	96.8	591.7	162.0	233.3	50.4	158.3	54.7		0.169	
Wax myrtle	933.3	258.6	1,150.0	356.4	800.0	239.0	800.0	398.8	808.3	220.7		0.919	
Yaupon	391.7	100.6	658.3	219.1	525.0	188.2	400.0	107.7	408.3	144.3		0.993	
Other species	4,250.0	1,120.5	4,033.3	842.3	4,750.0	1,097.3	3,458.3	621.4	4,483.3	553.9		0.973	
Total	6,250.0	1,239.4	6,125.0	1,056.2	6,666.7	1,266.9	4,891.7	895.4	5,858.3	646.4		0.974	
Post-trt (2002)													
Common persimmon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.000	0.014
Wax myrtle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.000	0.036
Yaupon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.103	0.123
Other species	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.000	0.062
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		1.000	0.005

TABLE 1 (continued)

Species	Treatment																	
	1b			2c			3			4			5			*P*-value[d]		
	x		SE	x		SE	x		SE	x		SE	x		SE	Yr	Trt[e]	Yr*trt
Post-trt (2003)																		
Common persimmon	375.0	A[f]	168.7	0.0	B	0.0	62.5	B	62.5	62.5	B	62.5	0.0	B	0.0	0.008	⩽0.001	
Wax myrtle	125.0	A	87.2	0.0	B	0.0	0.0	B	0.0	0.0	B	0.0	0.0	B	0.0	0.095	0.001	
Yaupon	125.0		87.2	187.5		105.4	0.0		0.0	0.0		0.0	0.0		0.0	0.034	0.103	
Other species	1,000.0		388.1	437.5		197.9	312.5		159.8	125.0		87.2	0.0		0.0	⩽0.001	0.062	
Total	1,625.0	A	469.8	625.0	B	232.6	375.0	BC	168.7	187.5	BC	105.4	0.0	C	0.0	⩽0.001	⩽0.001	

[a] Actual means presented; analyses conducted on square-root transformed data.
[b] Within-treatment year effect ($P \leqslant 0.001$): *Diospyros virginiana*, *Myrica cerifera*, Total.
[c] Within-treatment year effect ($P<0.05$): Total.
[d] Pre-treatment data analyzed for treatment effect only; post-treatment data analyzed for effects of year, treatment, and year x treatment interaction.
[e] When yr*trt interaction was significant, trt *P*-values represent within-year treatment effects.
[f] Means within rows followed by same letter do not differ (α=0.05).

stems ∃0.5 m tall during the first growing season. The year effect was not consistent across all treatments for density of total species ($F_{4,27}$ = 4.82, P = 0.005) and ranged from 1,625.0 trees/ha in treatment 1 to 0.0 trees/ha in treatment 5 during 2003. Density of yaupon ($F_{1,27}$ = 5.00, P = 0.034) and other species ($F_{1,27}$ = 15.80, $P \leqslant 0.001$) increased in most treatments during 2003. The year effect was not consistent among treatments for common persimmon ($F_{4,27}$ = 3.81, P = 0.014) and wax myrtle ($F_{4,27}$ = 3.00, P = 0.036). During 2003, common persimmon densities ranged from 375.0 trees/ha in treatment 1 to 0.0 trees/ha in treatments 2 and 5. Wax myrtle density increased during 2003 to 125.0 trees/ha in treatment 1 but remained at 0.0 trees/ha in all other treatments.

There was a year × treatment interaction for woody canopy coverage ($F_{4,27}$ = 3.82, P = 0.014) and herbaceous canopy cover ($F_{4,27}$ = 3.04, P = 0.034, Table 2). Woody coverage during the first growing season varied from a high of 19.5% in treatment 1 to lows of 2.8-3.5% in treatments 4 and 5. By the end of the second growing season, woody coverage showed a clear, negative association with treatment intensity, ranging from 71.0% in treatment 1 to 11.7% in treatment 5. During 2002, herbaceous coverage ranged from a high of 36.5% in treatment 2 to a low of 2.5-3.4% in treatments 4 and 5. By the end of the second growing season, herbaceous cover was similar on treatments 1-4 with a high of 60.5% in treatment 2; treatment 5 had considerably less herbaceous cover at 17.3%.

Pine survival differed by year and treatment (Table 3). Survival decreased about 2% on all treatments during 2003 ($F_{1,27}$ = 4.62, P = 0.041). Survival varied among treatments ($F_{4,27}$ = 0.72, P = 0.038) averaging about 85% in treatments 1-4 and 73% in treatment 5.

There was a within-treatment year effect on height ($F_{4,27}$ = 8.81, $P \leqslant 0.001$) and diameter ($F_{4,27}$ = 9.56, $P \leqslant 0.001$) of pine trees (Table 3). There were no differences in pine height or diameter during 2002 indicating that all seedlings were of equivalent size when planted. However, a positive association between treatment intensity and pine growth was evident by the end of the second growing season with trees in treatments 4 and 5 having greater heights and diameters than trees in all other treatments. Pine growth was greater in treatments receiving mechanical site preparation compared to the herbicide-only site preparation. The best pine growth was in the treatments combining chemical and mechanical treatments.

TABLE 2. Woody and herbaceous canopy coverage (%) for 5 pine plantation management regimes varying from low (1) to high (5) intensity at years 1 and 2 post-treatment (June 2002 and June 2003) in the Mississippi Lower Coastal Plain

	Treatment																	
	1[b]			2[c]			3c			4[c]			5[d]			P-value		
Forage type	x		SE	x		SE	x		SE	x		SE	x		SE	Yr	Trte	Yr*trt
Woody																		
2002	19.5	A[f]	1.7	8.5	AB	1.5	8.8	AB	1.2	3.5	B	0.5	2.8	B	0.4		0.110	0.014
2003	71.0	A	5.1	35.5	B	3.1	53.9	C	4.7	41.5	BC	3.8	11.7	D	1.7	⩽0.001	0.001	
Herbaceous																		
2002	26.7	A	1.7	36.5	A	4.5	20.1	A	2.2	3.4	B	0.6	2.5	B	0.6		⩽ 0.001	0.034
2003	50.6	A	1.9	60.5	A	3.4	48.8	A	3.1	48.8	A	3.3	17.3	B	1.9	⩽0.001	⩽0.001	

[a] Actual means presented; analyses conducted on square-root transformed data.
[b] Within-treatment year effect ($P \leqslant 0.01$): herbaceous; (P#0.001): woody.
[c] Within-treatment year effect ($P \leqslant 0.001$): herbaceous, woody.
[d] Within-treatment year effect ($P < 0.10$): herbaceous.
[e] When yr*trt interaction was significant, trt P-values represent within-year treatment effects.
[f] Means within rows followed by same letter do not differ ($\alpha > 0.05$).

TABLE 3. Survival (%), height (m), and diameter (mm) of pine trees for 5 pine plantation management regimes varying from low (1) to high (5) intensity during the first and second growing seasons (June 2002 and June 2003) and the end of the second growing season (January 2004) in the Mississippi Lower Coastal Plain[a]

	Treatment																	
	1[b]			2[b]			3[b]			4[b]			5[b]			P-value		
	x		SE	x		SE	x		SE	x		SE	x		SE	Yr	Trt[c]	Yr*trt
Survival																		
2002	84.3		8.4	86.4		5.5	88.2		5.4	87.1		6.9	74.6		11.4			
2003	84.3		8.4	85.7		5.6	85.4		4.4	86.1		6.7	71.4		9.6			
Combined	84.3	Ad	5.5	86.1	A	3.6	86.8	A	3.3	86.6	A	4.5	73.0	B	6.9	0.041	0.038	0.585
Height																		
2002	0.4		0.0	0.4		0.0	0.4		0.0	0.5		0.0	0.4		0.0		0.823	⩽0.001
2004	2.1	A	0.0	1.8	B	0.0	2.2	A	0.0	2.5	C	0.0	2.5	C	0.0	⩽0.001	0.001	
Diameter																		
2002	7.4	A	0.2	6.2	A	0.1	7.5	A	0.2	8.2	A	0.2	7.5	A	0.2		0.543	⩽0.001
2004	41.6	A	0.8	34.4	B	0.7	48.9	C	0.9	59.1	D	0.9	60.3	D	1.0	⩽0.001	⩽0.001	

[a] Actual means presented; analyses conducted on square root transformed data.
[b] Within-treatment year effect (*P*#0.001): height and diameter.
[c] When yr*trt interaction was significant, trt *P*-values represent within-year treatment effect.
[d] Means within rows followed by same letter do not differ (a>0.05).

DISCUSSION

A primary goal of site preparation is to reduce competing vegetation (Shiver and Martin, 2002). Herbaceous vegetation is often the most important component to control early in stand establishment due to its impact on pine survival and growth, and woody vegetation control is important from the standpoint of long-term yield limitation (Lauer et al., 1998). The chemical site preparation tank mixture was designed to target both of these vegetation components. The benefits from suppressing herbaceous and woody canopy cover during the first growing season were evident in the positive associations between management intensity and pine height and diameter by the end of the second growing season.

Control of the hardwood vegetative component is important for long-term pine growth (Shiver et al., 1991; Harrington et al., 1998). All treatments were successful in controlling woody stems during the first growing season. However, re-colonization of woody species was evident during the second growing season and treatment 1 had the greatest increase in woody stem density likely because that treatment did not receive an application of site preparation herbicides. Prior research also has documented relatively short-term effects (i.e., 2-3 growing seasons) of mechanical or chemical site preparation in combination with herbaceous weed control on vegetative communities (Blake et al., 1987; Keyser et al., 2003).

We could not identify why pine survival decreased during year two because of high variability in survival rates during the first year post-planting (Amateis et al., 1997). Sources of mortality during this period typically include seedling care at the nursery and planting site, length of seedling storage, planting crew quality, and first-year climatic conditions (Amateis et al., 1997). Pine survival was less on treatment 5, implying a treatment-related decrease. However, treatments 4 and 5 were operationally equivalent (i.e., treatment 5 had not received its second broadcast herbaceous control) when survival was measured. Two sites, with seedlings originating from the same source, had considerably less survival, 69 and 73%, compared to the other two stands with survival of 92 and 97%. Survival within treatment 5 was particularly low within the two lesser-survival stands. There were no topographic features on these two stands that would decrease survival (i.e., poorly drained areas) and rainfall was not above normal levels during the first growing season. Both of these stands were hand planted, thus survival decreases may be attributable to poor planting and/or poor seedling condition at the time of planting. Intensive management does not necessarily imply increased survival (South et al., 2001), although survival increases have been documented from mechanical site preparation followed by herbaceous weed control (Tiarks and Haywood, 1986) as well as mechanical and chemical site preparation followed by herbaceous weed control (Yeiser et al., 2004).

The combination site preparation treatments resulted in a 23% increase in pine height and a 44% increase in pine diameter as compared to the mechanical only and chemical only treatments. Pine height and diameter were less in treatment 2 than in treatments with mechanical site preparation, confirming the importance of mechanical subsoiling and bedding in the Mississippi Lower Coastal Plain, as reported by others (Amateis et al., 1997; Allen and Lein, 1998; Lauer et al., 1998).

The lack of differences in pine growth between treatment 4, receiving one year of broadcast herbaceous control, and treatment 5, receiving two years of broadcast herbaceous control was noteworthy. These results indicate that multiple years of herbaceous weed control were not necessary to maximize growth after two growing seasons. Differences in pine growth could develop in subsequent years, as complete vegetation control for multiple years has proven to promote greater pine growth (Pienaar et al., 1983; Cain, 1991; Miller et al., 1995; Borders and Bailey, 1997). However, it is typically not operationally feasible for most managers to broadcast vegetation control for multiple years due to high treatment costs, environmental concerns (Morrison and Meslow, 1983), and wood quality concerns (Clark and Schmidtling, 1989). Bacon and Zedaker (1987) reported that herbaceous weed control applied at the beginning of the second growing season provided the greatest release from competition, indicating that differences may become evident between treatments 4 and 5 during subsequent growing seasons.

Broadcast herbaceous control (i.e., treatments 4 and 5) promoted greater pine height and diameter growth indicating that complete herbaceous control was biologically more effective than banded control. Dougherty (1990) spot-sprayed 0.6-, 1.2-, 1.8-, and 2.4-m diameter circles around individual trees and reported that pine height and diameter increased significantly when competition was controlled (1.8-m around each tree. Treatments that received banded herbaceous controls in this study had only 0.8 m treated on either side of the tree, which may not be enough growing space to produce a competitive advantage.

CONCLUSIONS

Forest managers in the Southeast are concerned with the operational establishment of pine plantations that maximize timber production while meeting expectations of sustainable forestry programs. Management regimes including the combination of mechanical and chemical site preparation promoted the greatest pine growth in this study by controlling competing vegetation and providing soil amendments that potentially improved root development and nutrient availability. Mechanical subsoiling and bedding were essential on these sites for early increased pine growth, and chemical control was essential for control of woody species which likely will have long-term consequences for pine growth and yield. Broadcast herbaceous applications more effectively controlled competing vegetation and promoted greater pine growth than did banded applications, although there were no differences between one and two years of broadcast herbaceous control. Based on two years of post-treatment data, combination site preparation followed by one year of broadcast herbaceous weed control was the most effective management regime of those we evaluated.

REFERENCES

Allen, H.L. and S. Lein. 1998. Effects of site preparation, early fertilization, and weed control on 14-year old loblolly pine. Proceedings of the Southern Weed Science Society 51:104-110.

Amateis, R.L., H.E. Burkhart, and J. Liu. 1997. Modeling survival in juvenile and mature loblolly pine plantations. Forest Ecology and Management 90:51-58.

Bacon, C.G. and S.M. Zedaker. 1987. Third-year growth response of loblolly pine to eight levels of competition control. Southern Journal of Applied Forestry 11:91-95.

Blake, P.M., G.A. Hurst, and T.A. Terry. 1987. Responses of vegetation and deer forage following application of hexazinone. Southern Journal of Applied Forestry 11:176-180.

Borders, B.E. and R.L. Bailey. 1997. Loblolly pine - pushing the limits of growth. Consortium on Accelerated Pine Production Studies, University of Georgia, Technical Report 1997-1.

Cain, M.D. 1991. The influence of woody and herbaceous competition on early growth of naturally regenerated loblolly and shortleaf pines. Southern Journal of Applied Forestry 15:179-185.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39:388-394.

Clark, III, A.C. and R.C. Schmidtling. 1989. Effect of intensive culture on juvenile wood formation and wood properties of loblolly, slash, and longleaf pine. In: pp.

211-217. J.H. Miller (ed.). Proceedings of the Fifth Biennial Southern Silviculture Research Conference.

Dougherty, P.M. 1990. Survival and growth responses of loblolly pine to a range of competition control. Georgia Forestry Commission, Research Division, Georgia Forest Research Paper 81.

Glover, G.R. and B.R. Zutter. 1993. Loblolly pine and mixed hardwood stand dynamics for 27 years following chemical, mechanical, and manual site preparation. Canadian Journal of Forest Resources 23:2126-2132.

Harrington, T.B., P.J. Minogue, D.K. Lauer, and A.W. Ezell. 1998. Two-year development of southern pine seedlings and associated vegetation following spray-and-burn site preparation with imazapyr alone or in mixture with other herbicides. New Forests 15:89-106.

Haywood, J.D. and A.E. Tiarks. 1990. Eleventh-year results of fertilization, herbaceous, and woody plant control in a loblolly pine plantation. Southern Journal of Applied Forestry 14:173-177.

Keyser, P.D., V.L. Ford, and D.C. Guynn, Jr. 2003. Effects of herbaceous competition control on wildlife habitat quality in Piedmont pine plantations. Southern Journal of Applied Forestry 27:55-60.

Lauer, D.K., R.L. Muir, and G.R. Glover. 1998. Combining herbicide applications with mechanical site preparation. Proceedings of the Southern Weed Science Society 51:112-113.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS Institute, North Carolina, USA.

Miller, J.H., B.R. Zutter, S.M. Zedaker, M.B. Edwards, and T.A. Newbold. 1995. A regional framework of early growth response for loblolly pine relative to herbaceous, woody, and complete competition control: the COMProject. United States Forest Service General Technical Report SO-117.

Morrison, M.L. and E.C. Meslow. 1983. Impacts of forest herbicides on wildlife: toxicity and habitat alteration. Transactions of the North American Wildlife and Natural Resources Conference 48:175-185.

Pettry, D.E. 1977. Soil resource areas of Mississippi. Mississippi Agricultural and Forestry Experiment Station Information Sheet 1278.

Pienaar, L.V., J.W. Rheney, and B.D. Shiver. 1983. Response to control of competingvegetation in site-prepared slash pine plantations. Southern Journal of Applied Forestry 7:38-45.

SAS Institute. 2000. SAS/STAT User's Guide, Version 8. SAS Institute, North Carolina, USA.

Sedjo, R.A. and D. Botkin. 1997. Using forest plantations to spare natural forests. Environment 39(10):14-30.

Shiver, B.D., S.A. Knowe, M.B. Edwards, and W.N. Kline. 1991. Comparison of herbicide treatments for controlling common Coastal Plain Flatwoods species. Southern Journal of Applied Forestry 15:187-193.

Shiver, B.D. and S.W. Martin. 2002. Twelve-year results of a loblolly pine site preparation study in the Piedmont and Upper Coastal Plain of South Carolina, Georgia, and Alabama. Southern Journal of Applied Forestry 26:32-36.

Siry, J.P. 2002. Intensive timber management practices. In: pp. 327-340. D.N. Wear and J.G. Greis (eds.). Southern forest resource assessment. United States Forest Service, Southern Research Station, General Technical Report SRS-53.

Smith, D.M., B.C. Larson, M.J. Kelty, and P.M.S. Ashton. 1997. The practice of silviculture: applied forest ecology. Ninth edition. John Wiley and Sons, New York, USA.

South, D.B., J.L. Rakestraw, and G.A. Lowerts. 2001. Early gains from planting large-diameter seedlings and intensive management are additive for loblolly pine. New Forests 22:97-110.

Tiarks, A.E. and J.D. Haywood. 1986. *Pinus taeda* L. response to fertilization, herbaceous plant control, and woody plant control. Forest Ecology and Management 14:103-112.

Yeiser, J.L., T.L.L. Temple Chair, and A.W. Ezell. 2004. Oustar herbicide for efficient herbaceous weed control and enhanced loblolly pine seedling performance in the southeastern US. Forest Ecology and Management 192:207-215.

Zar, J.H., 1999. Biostatistical analysis. Fourth edition. Prentiss Hall, New Jersey, USA.

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