Effects of Herbaceous and Woody Plant Control on Longleaf Pine Growth and Understory Plant Cover

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ABSTRACT

To determine if either herbaceous or woody plants are more competitive with longleaf pine (*Pinus palustris* Mill.) trees, four vegetation management treatments—check, herbaceous plant control (HPC), woody plant control (WPC), and HPC+WPC—were applied in newly established longleaf pine plantings in a randomized complete block design in two studies. Prescribed fire was repeatedly applied across both study sites, and pine measurements were continued for 12 years. Pine survival was not significantly different among the four treatments in either study. In Study 1, pines were taller on HPC+WPC plots than on checks, and pine basal area and volume per ha were greater on HPC and HPC+WPC plots than on checks. Volume per ha ranged from 45 m^3/ha on checks to 70 m^3/ha on HPC+WPC plots. The WPC treatment was ineffective. In Study 2, there were no significant basal area and volume per ha differences among the four treatments. Volume per ha ranged from 119 m^3/ha on checks to 151 m^3/ha on HPC+WPC plots after 12 years. In the thirteenth growing season, HPC+WPC plots had more surface area covered in litter than did checks, and there was less grass cover on HPC plots than on checks in Study 1. In Study 2, litter and plant cover in the understory were not significantly different among the four treatments. With the application of fire, HPC remained effective when basal area per ha did not exceed 14 m^2/ha. WPC was not beneficial perhaps because prescribed fire was repeatedly applied making WPC unnecessary.

Keywords: hexazinone, *Pinus palustris* Mill., sethoxydim, triclopyr, vegetation management

Management of longleaf pine (*Pinus palustris* Mill.) plantations can be difficult, partly because longleaf seedlings may develop little aboveground for several years as the root system develops (Harlow and Harrar 1969). During this establishment period, the application of prescribed fire is a recommended cultural practice for controlling encroaching brush, brown-spot needle blight (caused by *Mycosphaerella dearnessii* M.E. Barr.) and to remove litter that smothers seedlings (Wahlenberg 1946, Croker and Boyer 1975).

Supplementary to fire use, chemical and mechanical treatments may increase survival of longleaf pine seedlings and promote early height growth (Boyer 1989, Brockway and Outcalt 2000). However, total vegetation control is not necessary for the management of longleaf pine regeneration (Nelson et al. 1985, Haywood 2000). In fact, reducing plant cover to about 50% is sufficient to ensure the early emergence of longleaf seedlings from the grass stage. By not attempting to eradicate all understory vegetation, plant species are retained on site (Kush et al. 1999). Since total control is not necessary, it becomes important to determine which type of plants competes with crop trees because cultural practices can be tailored to treat one group of vegetation and not another. This helps preserve native plants by treating only target vegetation and possibly reducing the number and amount of herbicides used.

Although longleaf pine seedlings respond to vegetation control during the first few years after planting (Haywood 2000, 2005), the long-term effects of these treatments have not been well-documented. Herein, the long-term effects of two vegetation management options were examined in two longleaf pine studies through 12 growing seasons on sites where prescribed fire was routinely applied-herbaceous plant control applied in the first two growing seasons; woody plant control applied in the first, second (in one study only), and fourth growing seasons, and a combination of both herbaceous and woody plant control. The objective was to determine how herbaceous and woody plant control affected survival and development of longleaf pine. In addition, the influence of treatments on understory vegetation was determined in the thirteenth growing season.

Methods

Study Site Descriptions

Study 1 is located on the Kisatchie National Forest (KNF) in central Louisiana at 92° 39′W, 31° 2′N, and 55 m above sea level on a gently sloping (0–12%) Beauregard silt loam (fine-silty, siliceous, superactive, thermic Plinthaquic Paleudult) and Gore silt loam (fine, mixed, active, thermic Vertic Paleudalf) complex (Kerr et al. 1980). The Beauregard forms broad flats and the Gore forms side slopes next to drainages. In the early 1960s, Study 1 was a range dominated by native bluestem grasses (*Andropogon* spp. and *Schizachyrium* spp.) and scattered brush. A slash pine (*P. elliottii* Engelm.) stand was established by direct seeding, which was clearcut harvested in the late 1980s, kept under cattle management, and prescribed fire was routinely applied to maintain the natural range vegetation. Grazing stopped in 1993, but the application of fire continued.

Study 2 is on two soil complexes on the KNF. The first one (92° 36′W, 31° 6′N at 55 m above sea level) is comprised of Ruston

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; millimeters (mm): 1 mm = 0.039 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; cubic meters (m^3): 1 m^3 = 35.3 ft^3; hectares (ha): 1 ha = 2.47 ac; kilograms (kg): 1 kg = 2.2 lb.

fine sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Paleudult) with a slope of 1–10% (Kerr et al. 1980). The other complex (92° 38′W, 31° 8′N at 66 m above sea level) is comprised of Beauregard silt loam and Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudult) with a slope of 1–5%. Before harvesting, Study 2 was a closed canopy, mature, loblolly pine (*P. taeda* L.)-hardwood forest. The understory vegetation was mostly hardwood trees, shrubs, and vines and scattered shade tolerant herbaceous plants.

The study sites are within the humid, temperate, coastal plain and flatwoods province of the West Gulf Region of the southeastern United States (McNab and Avers 1994). The climate is subtropical. During the 12-year period, December had the lowest average mean temperature of 10.3° C and August had the highest average mean temperature of 28.2° C (National Climatic Data Center 2012). Annual precipitation averaged 1,463 mm with 1,059 mm during the growing season, which included the months of March through November. Both studies are on uplands suitable for restoring longleaf pine forests (Turner et al. 1999).

Treatment Establishment

In Study 1, the vegetation was rotary mowed and the large woody debris was hand cleared in June 1997. In Study 2, the mature loblolly pine-hardwood forest on both complexes was clearcut harvested in 1996, roller drum chopped, and prescribed fire was applied by October 1997. Primarily grasses dominated the plant community in Study 1, and trees and shrubs dominated the plant community in Study 2 for the next 6 years (Haywood 2005). On plots that were only prescribed burned (checks), 1st-year herbaceous plant mass was 2,058 kg/ha oven-dried weight at Study 1 and 1,055 kg/ha at Study 2. After 4 years, tree and shrub stocking was 18,031 stems/ha with an average total height of 0.06 m and crown width of 0.03 m at Study 1, whereas at Study 2, stocking was 29,270 stems/ha with an average total height of 0.6 m and crown width of 0.3 m.

In 1997, four treatments were randomly assigned to the research plots in a randomized complete block design (Steel and Torrie 1980)—check, herbaceous plant control (HPC), woody plant control (WPC), and HPC+WPC. In both studies, the 16 research plots (four blocks by four treatments) each measured 22 by 22 m (0.048 ha) and contained 12 rows of 12 seedlings arranged in a 1.83- by 1.83-m spacing. The center 64 longleaf pine seedlings (eight rows of eight seedlings each) were the measurement plot. In Study 1, blocking was based on soils with two blocks established on each soil type. In Study 2, blocking was by complex (two blocks on each soil complex) and topographic location within each complex.

Longleaf pine seeds from a standard Louisiana seed source were sowed in containers in May 1997. The 28-week-old seedlings were planted on both sites in November 1997 using a planting dibble with a tip of the correct size and shape for the 3.8-cm-wide and 14-cm-deep root plug.

Two herbicides were used for HPC: sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) for controlling bluestem grasses and hexazinone (3-cyclohexyl-6-[dimethylamino]-1-methyl-1,3,5-triazine-2,4[1H, 3H]-dione) for general herbaceous plant control. In April of 1998 and 1999, the two herbicides were applied in 0.9-m bands over the rows of unshielded longleaf pine seedlings at Study 1. Within the 0.9-m bands, the rate of sethoxydim was 0.37 kg active ingredient (ai)/ha, and for hexazinone, the rate was 1.12 kg ai/ha. At Study 2, only hexazinone was banded in April 1998 and 1999 because sethoxydim was not needed for bluestem grass control.

In both studies, WPC was done with triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid) at 0.0048 kg acid equivalent/liter. The triclopyr was tank-mixed with surfactant and water and applied as a directed foliar spray to hardwood trees and shrubs in April 1998. In Study 2, the brush was retreated in June 1999, but Study 1 did not need retreating because an intense prescribed fire earlier in May 1999 top-killed most of the woody vegetation. Recovering brush was hand-felled in February 2001 at both studies.

Prescribed fire was routinely applied in both studies as a normal management practice. Fire management personnel with the KNF first set backfires to secure the boundaries of each site or complex. Then, the fire crew would set striphead fires with drip torches or spot fires using a helicopter-mounted ignition system until the entire site or complex was burned.

Prescribed fire was applied at Study 1 in May 1999 (18 months after planting), April 2001, May 2003, June 2005, June 2007, and May 2009. All six were intense fires, which are common in established grass rough (Haywood 2009, 2011).

In Study 2, the first prescribed fire was delayed until June 2000 (31 months after planting) because of a lack of grass development and subsequent poor fuel bed conditions. A wildfire in January 2003 burned Blocks 3 and 4, but the longleaf pines survived because this species commonly endures high-fire intensities (Haywood 2009, 2011). Prescribed fire was applied to the other two blocks in May 2003. The next three fires were set in May 2005, June 2007, and May 2009.

Sampling

Longleaf pine tree total height and diameter at breast height (dbh) measurements were taken at ages 7 and 12 years. Heights were measured with a calibrated pole at age 7 and with a laser instrument (Criterion 400 Survey Laser, Laser Technology, Inc., Centennial, CO) at age 12. Tree dbh was measured with a diameter tape. Total height and dbh were used to calculate outside-bark bole volume with Baldwin and Saucier's (1983) formulas.

In September of the thirteenth growing season, percent cover of litter and understory vegetation was estimated as five different taxa-grasses, forbs (which included grasslike-plants and ferns), trees, shrubs (which included blackberry [*Rubus* spp.]), and woody vines. The measurements were taken at five 1.83- by 1.83-m squares whose corners were the original planting locations for the longleaf pine seedlings. A square was located in the middle of each plot and in the center of each quarter section of the plot.

Data Analysis

In each study, number of longleaf pine per ha, average total height, basal area, and volume per tree, and basal area and volume per ha were compared among the four treatments using a randomized complete block design model at $\alpha = 0.05$ (SAS Institute, Inc., 1985). Analyses compared treatments at ages 7 and 12 years and the difference in growth and production over the 5-year period. Percent cover of litter in the thirteenth growing season was analyzed with the same model. However, percent understory plant cover was analyzed with an analysis of covariance model in which the covariate for tree and shrub cover was tree and shrub cover in the fourth growing season. For woody vines, the covariate was the number of vines per ha in the fourth growing season. For grass and forbs, the covariates

Table 1. For both studies, longleaf pine total height, basal area, and volume per tree after the seventh and twelfth growing seasons and for the change in values over the 5-year period.

		Total height (m)			Basal area (dm^2)			Volume (dm^3)		
		7 g.s.[a]	12 g.s.	Chg[a]	7 g.s.	12 g.s.	Chg	7 g.s.	12 g.s.	Chg
						Study 1				
Treatments[a]										
Check		1.8b	6.6b	4.8a	0.06b	0.59a	0.53a	1.5b	24.7a	23.2a
HPC[a]		2.5ab	7.4ab	4.9a	0.13ab	0.71a	0.58a	3.5ab	32.3a	28.8a
WPC[a]		2.0b	7.0ab	5.0a	0.07ab	0.64a	0.57a	1.9ab	27.8a	25.9a
HPC+WPC		2.8a	7.8a	5.0a	0.15a	0.73a	0.58a	4.1a	33.9a	29.8a
Analysis sources	df					P > *F*-values				
Block effect	3	0.0391	0.0415	0.1272	0.0405	0.0579	0.1491	0.0434	0.0400	0.0510
Treatments	3	0.0128	0.0417	0.2528	0.0176	0.1014	0.4032	0.0217	0.0519	0.0856
Error mean square	9	0.1351	0.2485	0.0381	0.0011	0.0061	0.0030	1.1582	18.5118	11.7484
						Study 2				
Treatments										
Check		5.0c	10.5b	5.5a	0.38b	1.23ab	0.85a	13.5b	70.2ab	56.7a
HPC		5.8ab	11.1ab	5.3a	0.46ab	1.16b	0.70b	17.7ab	68.9b	51.2a
WPC		5.1bc	10.8ab	5.7a	0.43b	1.27ab	0.84ab	15.3b	73.6ab	58.3a
HPC + WPC		6.0a	11.6a	5.6a	0.60a	1.41a	0.81ab	22.4a	85.1a	62.7a
Analysis sources	df					P > *F*-values				
Block effect	3	0.3714	0.1628	0.1179	0.2686	0.2204	0.3733	0.2129	0.1257	0.1368
Treatments	3	0.0051	0.0403	0.0802	0.0051	0.0421	0.0460	0.0052	0.0422	0.0719
Error mean square	9	0.1186	0.2070	0.0357	0.0039	0.0101	0.0046	6.9089	52.6711	27.6753

[a] All treatments were repeatedly prescribed burned as a normal management activity, herbaceous plant control (HPC), woody plant control (WPC), growing season (g.s.), change in variable value over the 5-year period (Chg), and within columns, treatment means followed by the same letter are not significantly different based on Tukey's Studentized Range Test at $\alpha = 0.05$.

were percent cover in the third growing season for Study 1 and fourth growing season for Study 2. If there were significant differences among the four treatments, mean comparisons were made with Tukey's Studentized Range Test at $\alpha = 0.05$. Percentages were arcsine transformed before analysis to equalize variances (Steel and Torrie 1980).

Results

Longleaf Pine

In Study 1, longleaf pine total height on HPC+WPC plots was significantly greater than on checks and WPC plots after seven growing seasons (Table 1). The treatment combination also resulted in greater basal area and volume per tree than on checks. However, after 12 growing seasons, the treatment combination had greater pine total height compared only to checks. There were no treatment differences in basal area and volume per tree at age 12 years, and changes in total height, basal area, and volume per tree over the 5-year period were not significantly different among the four treatments. After 12 years, total height ranged from about 7 m on checks to 8 m on HPC+WPC plots, basal area per tree ranged from 0.6 dm^2 on checks to 0.7 dm^2 on HPC+WPC plots, and volume per tree ranged from 25 dm^3 on checks to 34 dm^3 on HPC+WPC plots.

In Study 2, longleaf pine total height, basal area, and volume per tree were significantly greater on HPC+WPC plots than on checks and WPC plots, and total height on HPC plots was greater than on checks after seven growing seasons (Table 1). At age 12 years, total height was greater on HPC+WPC plots than on checks, and the treatment combination had greater basal area and volume per tree than the HPC plots. Change in basal area per tree over the 5-year period was greater on checks than on HPC plots. After 12 years, total height ranged from about 11 m on checks to 12 m on HPC+WPC plots, basal area per tree ranged from 1.2 dm^2 on HPC plots to 1.4 dm^2 on HPC+WPC plots, and volume per tree ranged from 69 dm^3 on HPC plots to 85 dm^3 on HPC+WPC plots.

Longleaf pine stocking after 12 growing seasons was not significantly affected by postplant vegetation control in either study (Table 2). Survival ranged from 60% on checks to 69% on HPC+WPC plots in Study 1 and 57% on checks to 71% on HPC plots in Study 2. Most mortality occurred in the first growing season (Haywood 2005), and survival decreased by only three percentage points in both studies from the sixth through twelfth growing seasons.

In Study 1, pine basal area and volume per ha were significantly greater on HPC+WPC plots than on checks at age 7 and 12 years (Table 2). Likewise, change in basal area and volume per ha over the 5-year period was greater on the treatment combination than on checks. The HPC treatment also resulted in greater basal area and volume per ha than on checks after 12 growing seasons, and change in volume per ha over the 5-year period was greater on HPC plots than on checks. After 12 years, basal area per ha ranged from about 11 m^2/ha on checks to 15 m^2/ha on HPC+WPC plots, and volume per ha ranged from 45 m^3/ha on checks to 70 m^3/ha on HPC+WPC plots. In addition, the significant block effects for total height, volume per tree, and basal area and volume per ha through 12 years (Tables 1 and 2) might have resulted because the Beauregard silt loam is considered a more productive soil than the Gore silt loam (Kerr et al. 1980).

In Study 2, there were no statistical differences among the four treatments in basal area per ha at ages 7 or 12 years (Table 2). Volume per ha was greater on the treatment combination than on the check after 7 years, but not after 12 years. Change in basal area and volume per ha over the 5-year period was not statistically different among the four treatments. After 12 years, basal area per ha ranged from about 21 m^2/ha on checks to 25 m^2/ha on HPC+WPC plots, and volume per ha ranged from 119 m^3/ha on checks to 151 m^3/ha on HPC+WPC plots.

Understory Vegetation

In the thirteenth growing season at Study 1, the HPC+WPC plots had significantly greater surface area covered in litter (22%)

Table 2. For both studies, longleaf pine stocking, basal area, and volume per ha after the seventh and twelfth growing seasons and for the change in values over the 5-year period.

		Number of pines per ha	Basal area (m^2/ha)			Volume (m^3/ha)		
		12 g.s.[a]	7 g.s.	12 g.s.	Chg[a]	7 g.s.	12 g.s.	Chg
		Study 1						
Treatments[a]								
Check		1798a	1.2b	10.6b	9.4b	2.9b	44.6b	41.7b
HPC[a]		1962a	2.5ab	13.9a	11.4ab	6.9ab	63.0a	56.1a
WPC[a]		2020a	1.5ab	12.9ab	11.4ab	3.7ab	56.0ab	52.3ab
HPC+WPC		2055a	3.0a	15.0a	12.0a	8.6a	70.0a	61.4a
Analysis sources	df			P > *F*-values				
Block effect	3	0.5069	0.0238	0.0037	0.0050	0.0336	0.0049	0.0030
Treatments	3	0.4812	0.0185	0.0098	0.0158	0.0285	0.0096	0.0069
Error mean square	9	57,956.6259	0.5311	1.9906	0.8415	5.9506	66.3004	35.2523
		Study 2						
Treatments								
Check		1693a	6.5a	20.8a	14.3a	23.1b	118.8a	95.7a
HPC		2114a	9.9a	24.7a	14.8a	37.9ab	146.7a	108.8a
WPC		1798a	7.8a	22.7a	14.9a	27.6ab	131.5a	103.9a
HPC+WPC		1775a	10.6a	24.9a	14.3a	39.7a	150.9a	111.2a
Analysis sources	df			P > *F*-values				
Block effect	3	0.3352	0.7636	0.8978	0.7965	0.6716	0.8005	0.8378
Treatments	3	0.1101	0.0662	0.4134	0.9529	0.0482	0.3294	0.6350
Error mean square	9	50,910.9180	4.0661	14.1567	3.3697	64.9584	656.2110	316.3644

[a] All treatments were repeatedly prescribed burned as a normal management practice, herbaceous plant control (HPC), woody plant control (WPC), growing season (g.s.), change in variable value over the 5-year period (Chg), and within columns, treatment means followed by the same letter are not significantly different based on Tukey's Studentized Range Test at $\alpha = 0.05$.

than checks (10%; Probability (P)>F-value (F) = 0.024). HPC (18%) and WPC (14%) plots had intermediate litter cover. HPC plots had less grass cover (14%) than checks (32%) (P>F = 0.045). There was intermediate grass cover on the WPC (27%) and HPC+WPC (22%) plots. Percent cover of forbs, shrubs, trees, and woody vines was not significantly different among the four treatments, and forb, shrub, tree, and woody vine cover averaged 13, 3, 4, and 2%, respectively, across all four treatments.

In Study 2, percent cover of litter, grasses, and forbs was not statistically different among treatments and averaged 61, 4, and 11%, respectively, across all four treatments. Cover of shrubs, trees, and woody vines was also not significantly different among treatments, and shrub, tree, and woody vine cover averaged 24, 14, and 2%, respectively, across all four treatments.

Discussion

Hexazinone and sethoxydim were banded over the planted rows of pine seedlings in the first two growing seasons for HPC. Directed applications of triclopyr were applied in the first growing season in Study 1 and in the first and second growing seasons in Study 2 followed by hand-felling in the fourth growing season in both studies for WPC. Because of chemical and mechanical vegetation control, longleaf pine basal area and volume per tree were greater on HPC+WPC plots than on checks through seven growing seasons. However, after 12 years, basal area and volume per tree were no longer statistically different between the check and HPC+WPC plots and there was no difference in average growth rates over the 5-year period between the treatment combination and checks in either study. There were also no significant survival differences among treatments. However, there was enough difference in average tree size and survival among the check, HPC, and HPC+WPC plots that when basal area and volume were scaled up to the ha the HPC and HPC+WPC plots had statistically greater basal area and volume per ha production than checks through 12 years at Study 1. The benefit of HPC at Study 1 transpired even though the treatment intentionally did not eradicate all of the herbaceous vegetation. This demonstrated that HPC practices applied at young ages can influence long-term production of planted longleaf pine if stand density expressed as overstory basal area is less than 14 m^2/ha (61 ft^2/ac) through 12 growing seasons. I believe that the greater stand density reached at Study 2 (23 m^2/ha or 101 ft^2/ac) caused individual tree development to converge across the four treatments resulting in no significant basal area and volume per hectare differences among treatments after 12 years.

WPC alone was not effective in either study in central Louisiana. In the first six growing seasons, WPC was also believed to be ineffective at influencing longleaf pine development (Haywood 2005). WPC was not beneficial as a supplementary vegetation control practice because prescribed fire was repeatedly applied and supplementary woody plant control treatments were not necessary.

Another factor affecting treatment responses by longleaf pine were soils at Study 1, which were expressed as significant block effects for total height, volume per tree, and basal area and volume per ha through 12 years (Tables 1 and 2). In addition, a small sample size (only four blocks were established) and natural variability may have contributed to the insignificant treatment differences for Study 2.

As the overstory basal area of longleaf pine stands increases, herbaceous plant production decreases (Wolters 1981, 1982). Similarly, in Study 1, the checks, which had shorter trees and less basal area per ha than on HPC-WPC plots, also had the least litter cover (10%) but the most grass cover (32%) among treatments in the thirteenth growing season. In Study 2, there were no treatment differences in stand basal area, litter, or herbaceous plant cover. Study 1 was generally a less productive site than Study 2, and checks at Study 2 had nearly twice the basal area per ha and 6 times more litter cover than checks at Study 1. However, checks at Study 1 had 2.6 times more herbaceous plant cover than checks at Study 2.

Herbaceous plant cover was 79% on checks in the third growing season at Study 1 and 52% in the fourth growing season at Study 2

(Haywood 2005). Prescribed fire removes litter and thereby should benefit herbaceous plant production (Grelen and Epps 1967), and burning probably helped maintain herbaceous plant cover on check plots at both Study 1 (45%) and Study 2 (17%) into the thirteenth growing season as the pine stands developed. Thinning the stands might further promote the herbaceous plant community (Grelen and Enghardt 1973).

Nevertheless, where prescribed fire is applied, application of HPC treatments at young ages may continue to influence stand production for years after treatments cease at least where basal areas per ha are less than 14 m^2/ha even though the HPC treatments do not completely control herbaceous vegetation.

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