Available online at www.sciencedirect.com
SCIENCE DIRECT
Forest Ecology and Management 214 (2005) 384–397
Forest Ecology and Management
www.elsevier.com/locate/foreco

Effects of herbaceous and woody plant control on *Pinus palustris* growth and foliar nutrients through six growing seasons

James D. Haywood *

USDA Forest Service, Southern Research Station, RWU 4111, Alexandria Forestry Center, 2500 Shreveport Highway, Pineville, LA 71360, USA

Received 1 October 2004; received in revised form 29 April 2005; accepted 29 April 2005

Abstract

To determine if either herbaceous or woody plants are more competitive with longleaf pine (*Pinus palustris* P. Mill.) seedlings, two vegetation management treatments—herbaceous plant control (HPC, No or Yes) and woody plant control (WPC, No or Yes) were applied in newly established longleaf pine plantings in a randomized complete block 2 × 2 factorial design in two studies ($\alpha = 0.05$). Both studies were broadcast prescribed burned as a normal management practice and the soils were of moderate texture. In the fourth growing season and 2 years after treatments ceased in Study 1, the HPC plots had more herbaceous plant productivity than the no HPC (NHPC) plots and arborescent vegetation had recovered from the WPC treatment. In Study 2, herbaceous plant productivity was less on the HPC plots than on the NHPC plots and the WPC plots had more herbaceous plant productivity and less arborescent vegetation than the no WPC plots. In both studies, HPC significantly increased height growth of the longleaf pine trees although total control of herbaceous plants was neither attempted nor achieved. The WPC treatment did not affect longleaf pine height growth. After six growing seasons, the longleaf pine trees averaged 0.9, 1.5, 1.1, and 1.7 m tall on the Burn only, Burn-HPC, Burn-WPC, and Burn-WPC–HPC treatments, respectively, in Study 1. In Study 2, the longleaf pines averaged 3.8, 4.8, 3.9, and 4.8 m tall on the Burn only, Burn-HPC, Burn-WPC, and Burn-WPC–HPC treatments, respectively. Herbaceous plant control reduced Mg concentrations in the living longleaf pine needles in both studies. Foliar P was generally deficient. Overall, however, the longleaf pine foliage had good nutritional balance on these moderately textured soils.

Keywords: Container seedlings; Hexazinone; Longleaf pine; *Pinus palustris* P. Mill; Sethoxydim; Triclopyr; Vegetation management

1. Introduction

Ideally, retention of longleaf pine (*Pinus palustris* P. Mill.) trees after establishing regeneration either through the shelterwood with reserves or group selection methods better sustains the long-term ecological character of the longleaf pine ecosystem than removal of the shelterwood or clearcutting (Boyer, 1993; Palik et al., 1997; Ross et al., 1997; Brockway and Outcalt, 1998). However, species composition and stand structure appropriate for

* Tel.: +1 318 473 7226; fax: +1 318 473 7273.
E-mail address: dhaywood@fs.fed.us.

0378-1127/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2005.04.023

shelterwood, group selection, or singletree selection are not always present on sites where restoring longleaf pine is the management objective. When a site is open grassland or a longleaf pine seed source is not present in the overstory, the best option for reestablishing longleaf pine is removal of the woody vegetation, site preparation, and planting.

Management of longleaf pine plantings can be difficult partly because it may develop little above ground for several years as the root system develops (Harlow and Harrar, 1969). The bunch of needles at the soil surface resembles a clump of grass; hence the term "grass stage" to describe the juvenile period of growth. During this establishment period, prescribed burning is a recommended cultural practice for controlling encroaching brush and brown-spot needle blight (caused by *Mycosphaerella dearnessii* M.E. Barr.) and removing litter that smothers seedlings (Wahlenberg, 1946; Croker and Boyer, 1975).

Supplementary to burning, chemical and mechanical treatments may increase survival of longleaf pine seedlings and speed early height growth (Barnett, 1989; Boyer, 1989; Loveless et al., 1989; Brockway and Outcalt, 2000). Total vegetation control is not necessary for the management of longleaf pine regeneration (Nelson et al., 1985). Reducing plant cover to about 50% is sufficient to insure the early emergence of longleaf seedlings from the grass stage (Haywood, 2000), and by not attempting to eradicate vegetation, plant species are not lost from the site (Kush et al., 1999).

Although longleaf pine seedlings respond to vegetation control, are either herbaceous or woody plants more competitive with longleaf pine during stand establishment? Herein, I examine two options for managing newly established longleaf pine plantations through six growing seasons on prescribe burned sites—herbaceous plant control (No or Yes) and woody plant control (No or Yes)—to determine how herbaceous and woody vegetation affect survival of longleaf pine seedlings and height growth. It is 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 not treating non-target vegetation and keeps unnecessary herbicides out of the environment. In addition, I determine how treatments affect understory vegetation and the nutrient content of the longleaf pine foliage. Although longleaf pine is not normally managed outside its natural range, vegetation control practices are used worldwide. Vegetation management studies in seedling stands usually do not continue for 6 years, and they normally do not examine which component of the plant community most affects growth of crop trees.

2. Methods

2.1. Study sites

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 with mean January and July temperatures of 8 and 28 °C, respectively (Louisiana Office of State Climatology, 2002). Annual precipitation averages 1525 mm with more than 965 mm during the 250-day growing season, which is from 10 March to 15 November (the late winter and fall dates with a 50% probability of a freeze). Both studies are on loamy dry-mesic uplands suitable for restoring longleaf pine forests (Turner et al., 1999).

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, thermic Plinthaquic Paleudult) and Gore very fine sandy loam (fine, mixed, 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 as described by (Duvall, 1962). A natural mixed pine forest developed, which was clearcut harvested in the late 1980s, kept under cattle management, and repeatedly prescribed burned to maintain the natural range vegetation. Grazing stopped in 1993, but prescribed burning 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 soil (fine-loamy, siliceous, thermic Typic Paleudult) with a slope of 1 to 10%. The other complex (92 °38′W, 31 °8′N at 66 m above sea level) is comprised of Beauregard and Malbis (fine-loamy, siliceous, thermic Plinthic Paleudult) fine sandy loams with a slope of 1 to 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.

2.2. Study establishment

In Study 1, the herbaceous and scattered arborescent vegetation was rotary mowed and the large woody debris 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 burned 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.

In 1997, four combinations of two vegetation management treatments, herbaceous plant control (HPC) at two levels (No or Yes) and woody plant control (WPC) at two levels (No or Yes), were randomly assigned to the research plots in a randomized complete block 2 × 2 factorial design (Steel and Torrie, 1980). In both studies, the 16 research plots (four blocks by four treatment combinations) each measured 22 m × 22 m (0.048 ha) and contained 12 rows of 12 seedlings arranged in a 1.83 m × 1.83 m spacing. The center 64 longleaf pine seedlings (8 rows of 8 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.

The container grown longleaf pine seedlings that originated from a standard Louisiana seed source were started in May 1997, and the 28-week-old seedlings were planted on both sites in November 1997 using a punch of the correct size for the root plug.

I used two herbicides for the HPC treatment: 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 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-pyridinyloxyacetic 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 arborescent vegetation in April 1998. In Study 2, the brush was retreated in June 1999, but Study 1 did not need retreating because an intense prescribed burn earlier in May 1999 top-killed most of the woody vegetation. Recovering brush was hand-cut in February 2001 on both studies.

Both studies were prescribed burned as a normal management practice. Fire management personnel with the KNF first set backfires to secure the boundaries of each site or complex. Then, either the ground crew would set striphead fires or spot fires would be set using a helicopter-mounted ignition system. The entire site or complex was burned.

Study 1 was prescribed burned in May 1999 (18 months after planting), April 2001, and May 2003. All three were intense fires, which are common in established grass rough (Haywood, 2002). Fire intensity was not measured in the first burn, but the next two burns consumed 6175 kg/ha of ovendried mass and generated a Byram's fire intensity of 508 kJ/s/m on average.

In Study 2, the first burn was delayed until June 2000 (31 months after planting), because of a lack of grass development and subsequent poor fuel bed conditions. The fire consumed about 700 kg/ha of available fine fuels and generated a fire intensity of 60 kJ/s/m. A wildfire in January 2003 burned blocks 3 and 4, but the longleaf pines survived because this species commonly endures high fire intensities (Haywood, 2002). The other two blocks were burned in May 2003; the fire consumed 4620 kg/ha of ovendried mass and generated a fire intensity of 252 kJ/s/m.

2.3. Climatic conditions

Following planting in November 1997, there was a mild to severe drought from May to August of the first

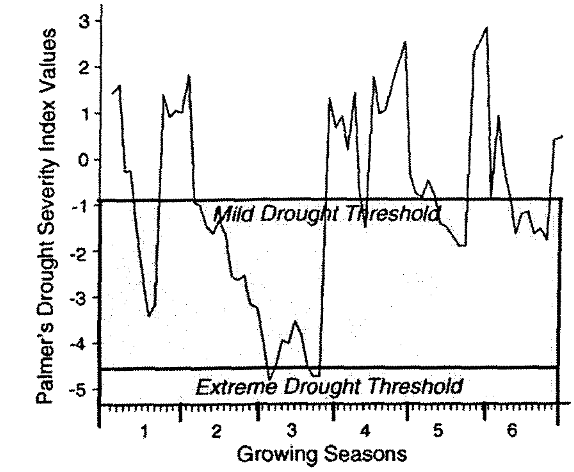

Fig. 1. Monthly Palmer Drought Severity Index values for central Louisiana from 1998 to 2003 in the first to sixth growing seasons.

growing season in 1998 based on Palmer Drought Severity Index (PDSI) (Fig. 1) (Louisiana Office of State Climatology, 2002, National Climatic Data Center, 2004). Drought conditions again prevailed from February 1999 to October 2000 with conditions becoming severe to extreme. In 2001, climatic conditions were more normal, but mild to moderate drought conditions redeveloped in May to September 2002 and in May to October 2003. Based on PDSI values, drought conditions occurred 54% of the time in central Louisiana from 1998 to 2003, but prevailed 63% of the time during the six growing seasons of 1998–2003.

2.4. Sampling

In both studies, longleaf pine survival counts were taken after each growing season in 1998–2003. Longleaf pine height measurements were taken after the second to sixth growing seasons in 1999–2003 because none of the seedlings was out of the grass stage the first year; that is, all of the seedlings were less than 12 cm tall (Wahlenberg, 1946; Boyer, 1989). Heights were measured with a calibrated rod to the nearest cm after the second growing season and to the nearest 3 cm thereafter. In Study 1, foliage of the longleaf pines was examined to determine percentage of needles infected with brown-spot needle blight when heights were taken, and the estimates were made to the nearest percent. Herbaceous plant cover within a 0.5 m radius of each longleaf pine seedling was estimated after the second to sixth growing seasons. Cover was quantified as the percentage of the 0.5 m radius circle shaded by herbaceous vegetation if the sun was directly overhead. Similar measurements were taken in Study 2, except the herbaceous plant estimates ceased after the third growing season in 2000 and the brown-spot needle blight estimates ceased after the fourth growing season in 2001.

In both studies, living herbaceous, arborescent vegetation (trees, shrubs, and blackberry (*Rubus* spp.), and vines were sampled in June 1998 on five 0.2 m^2 subplots per measurement plot. A subplot was located in the middle of the plot and in the center of each quarter section of the plot. The samples were dried at 80 °C to determine ovendried mass. Total herbaceous biomass (live and dead) was collected in April 2000 (preburn) at Study 2 and April 2001 (preburn) at Study 1.

In August 2001, percent herbaceous plant cover was estimated by taxa (grasses, grass-likes, and forbs) at both studies. Fern cover was too low to estimate, and so, ferns were included in the forb taxon. In addition, arborescent plants and woody vines were surveyed on five 4 m^2 subplots that were superimposed over the 0.2 m^2 subplots. The arborescent plant stems were counted at groundline to determine stocking and heights and crown widths were recorded.

Longleaf pine needles were collected from current-year flushes in the upper third of the tree crown during January 2004 at both studies. Samples were taken from five trees per plot; the sample trees were from the tallest 25% of the population. One of the selected trees was located near each of the 0.2 m^2 subplots. The needles were oven-dried at 70 °C, ground in a Wiley mill, and sieved through a 2 mm screen before determining percent C and N with a LECO CNS-2000 gas analyzer. Additional prepared sample was digested in acid before quantifying the concentrations of Ca, K, and Mg with a Perkin-Elmer 2100 atomic absorption spectrophotometer and the concentration of P with a Hewlett-Packard 8453 colorimetric spectrophotometer.

2.5. Data analysis

In each study, percent survival of longleaf pine, percent of longleaf pines in the grass stage, longleaf pine total height, percent herbaceous plant cover, and percent brown-spot needle blight were compared between treatments using a repeated measures randomized complete block 2 × 2 factorial design model ($\alpha = 0.05$) (SAS Institute Inc., 1985). For stand age and interaction-with-age (AGE–HPC, AGE–WPC, and AGE–WPC–HPC) effects, the Huynh–Feldt correction was used in tests of significance. Percentages were arcsine transformed before analysis (Steel and Torrie, 1980).

If treatments influenced emergence from the grass stage, they also might affect tree height distribution, but comparing only heights of trees out of the grass stage is not very helpful once the majority of trees have already emerged (Haywood, 2002). Therefore, besides the analyses for all longleaf pine, I subdivided the longleaf pine population into quartiles and compared heights among the tallest 25%, middle 50%, and shortest 25% of the population to determine if treatment effects varied among these subpopulations.

For each study, herbaceous and woody plant variables were analyzed using a randomized complete block 2 × 2 factorial design model ($\alpha = 0.05$) (SAS Institute Inc., 1985). The variables were ovendried mass of living herbaceous plants and woody vegetation in June 1998 (for both studies) and total ovendried mass of herbaceous plants in April 2000 (Study 2) or April 2001 (Study 1). I also analyzed percent cover by taxon (grass, grass-likes, and forbs); stocking, height, and crown width of arborescent plants; and stocking of vines in August 2001. Likewise, I analyzed the percent C and N and g/kg of P, K, Ca, and Mg found in the living longleaf pine foliage. Stocking means and nutrient concentrations were logarithmically transformed (log(Y)) to equalize variances, and percentages were arcsine transformed before analysis (Steel and Torrie, 1980).

3. Results and discussion

3.1. Longleaf pine survival and disease

First-year survival averaged 79% in Study 1 and 67% in Study 2 (Fig. 2). The HPC or WPC treatments did not affect survival (Table 1), and Ramsey et al., 2003 also reported that weed control did not influence

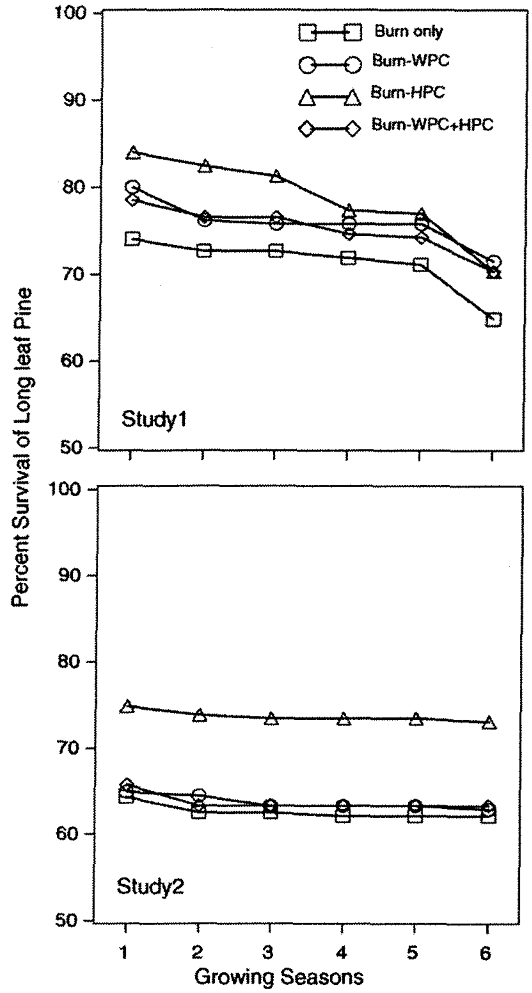

Fig. 2. Percent survival of planted longleaf pines in two studies in central Louisiana by treatment combination: burn only; burn-woody plant control (WPC); burn-herbaceous plant control (HPC); and Burn-WPC + HPC.

longleaf pine survival after two growing seasons. Survival decreased significantly with stand age in both studies. However, there was not a precipitant loss of seedlings after the first year, although I observed that the prescribed burn in the sixth growing season killed some of the longleaf pines at Study 1 (Fig. 2). This implies that the weakest longleaf pine seedlings died in the first growing season. After 6 years, survival averaged 69% in Study 1 and 65% in Study 2.

In Study 1, the percentage of longleaf pine needles infected with brown-spot needle blight increased from 1.2% after the second growing season to 3.6% after

Table 1
By study, degrees of freedom, probabilities of a greater F-value and error mean squares for percent longleaf pine survival, percentage of longleaf pines in the grass stage, total height of all longleaf pine trees through six growing seasons, and percent competing plant cover for ages 1 to 6 years in Study 1 and ages 2 and 3 years in Study 2

Sources in the repeated measures analyses	d.f.[a]	$P > F$-values			
		Longleaf pine			Herbaceous plant cover (%)
		Survival (%)	Grass-stage (%)	Total height (m)	
Study 1					
Block effect	3	0.2566	0.3352	0.0860	0.4323
HPC[b]	1	0.1540	0.0009	0.0022	0.0645
WPC[b]	1	0.9189	0.6669	0.3327	0.0874
WPC × HPC interactions	1	0.0944	0.6726	0.6720	0.7603
Error mean square	9	0.01696[d]	0.03741[d]	0.09004	0.01765[d]
Within subjects[c]					
Stand age (years)	5	<0.0001	<0.0001	<0.0001	<0.0001
Age × Blocks	15	0.9067	0.0937	0.0269	0.0035
Age × HPC	5	0.3953	0.0001	0.0002	<0.0001
Age × WPC	5	0.3998	0.0971	0.1980	0.0725
Age × WPC × HPC	5	0.6024	0.9086	0.8300	0.8254
Error (time) mean square	45	0.00149[d]	0.00724[d]	0.01613	0.00345[d]
Study 2					
Block effect	3	0.3159	0.2247	0.0299	0.0822
HPC[b]	1	0.1154	0.0024	0.0002	0.0002
WPC[b]	1	0.1793	0.9011	0.6295	0.1642
WPC × HPC interactions	1	0.1079	0.8709	0.9323	0.8175
Error mean square	9	0.02669[d]	0.01026[d]	0.25097	0.01878[d]
Within subjects[c]					
Stand age (years)	5	0.0005	<0.0001	<0.0001	0.2806
Age × Blocks	15	0.5466	0.0143	0.0014	0.6478
Age × HPC	5	0.8369	<0.0001	<0.0001	<0.0001
Age × WPC	5	0.9451	0.3664	0.6454	0.3450
Age × WPC × HPC	5	0.4918	0.4166	0.9115	0.8583
Error (time) mean square	45	0.00011[d]	0.00325[d]	0.01154	0.00157[d]

[a] In Study 2, the degrees of freedom for longleaf pines out of the grass stage were 3, 9, 3, 3, 3, and 27 for stand age, age × block, age × fertilization, age × treatment, age × fertilization × treatment, and error (time) mean square, respectively; and for herbaceous plant cover the degrees of freedom were 1, 3, 1, 1, 1, and 9 for stand age, age × block, age × fertilization, age × treatment, age × fertilization × treatment, and error (time) mean square, respectively.

[b] HPC: herbaceous plant control and WPC: woody plant control.

[c] For age and interactions-with-age effects, the Huynh–Feldt correction was used in tests of significance. The correction made minor differences in the probabilities.

[d] Percentages were arcsine transformed into radians before analysis.

five growing seasons across all treatments (data not shown). A few longleaf pine seedlings in the original grass rough were mowed down before plot establishment, and these trees may have served as an initial fungal source (Cordell et al., 1989). Once the fungus is established, it can intensify and spread although infection rates decreased to less than 1% after six growing seasons as the new growth became less accessible to rainsplashed conidiospores. The HPC and WPC treatments did not significantly change the rates of infection, and the rates of infection were too minor to affect overall stand development (Croker and Boyer, 1975). In Study 2, the infection rate never exceeded 1% (data not shown). Brown-spot needle blight levels are normally low on sites where longleaf pine is not already present, but windborne ascospores may have infected the seedlings in the nursery or after outplanting.

3.2. Longleaf pine emergence from the grass stage

None of the longleaf pine seedlings emerged from the grass stage in the first growing season. However, after two growing seasons, HPC significantly increased emergence with 28 and 5% of the seedlings on the HPC and no HPC (NHPC) plots emerging in Study 1 and 99 and 87% of the seedlings on the HPC and NHPC plots emerging in Study 2, respectively (Fig. 3). Ramsey et al., 2003 also found that longleaf pine seedlings were not out of the grass stage after the first growing season, but 78 and 50% of the seedlings emerged in the second growing season on weeded and control plots, respectively. In both studies, WPC did not significantly affect emergence from the grass stage.

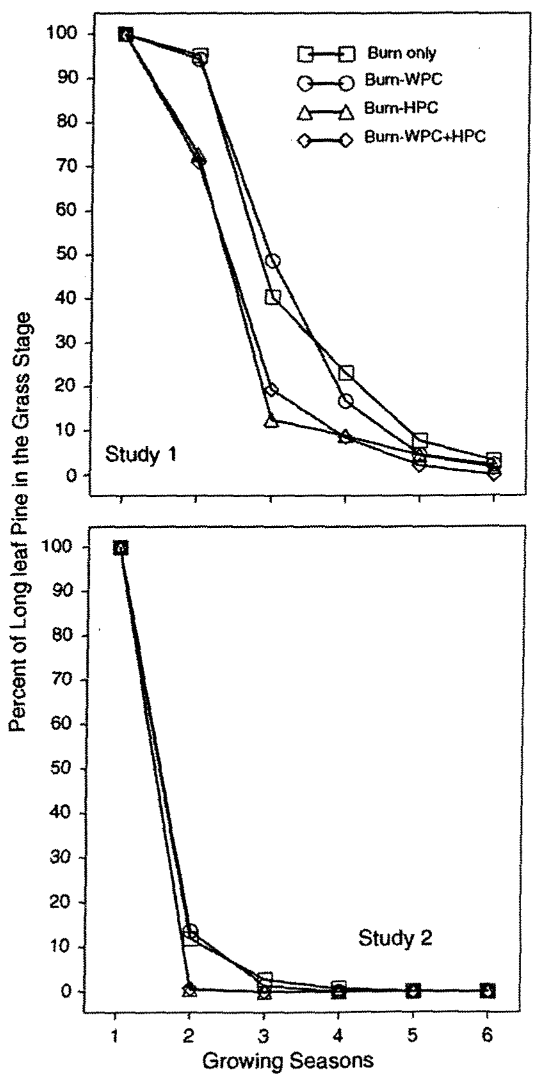

Fig. 3. Percent of longleaf pine in the grass stage in two studies in central Louisiana by treatment combination: burn only; burn-woody plant control (WPC); Burn-herbaceous plant control (HPC); and burn-WPC + HPC.

There were also significant stand age and AGE–HPC interactions influencing emergence (Table 1). In Study 1, HPC significantly increased the rate of emergence through three growing seasons—84% on the HPC and 55% on the NHPC plots (Fig. 3). After 4 years, emergence was no longer significantly different and averaged 86% across all treatments. By age 6 years, emergence averaged 98% in Study 1. In Study 2, treatment differences in emergence were minor after three growing seasons and averaged 99%. All surviving trees were out of the grass stage after 6 years. Haywood, 2000 found that vegetation management in a grass-dominated cover no longer influenced emergence of planted longleaf pine seedlings after 5 years.

3.3. Longleaf pine height growth

In both studies, HPC, stand age, and an AGE–HPC interaction significantly affected total height of all longleaf pine trees (Table 1). Therefore, HPC continuously influenced height growth well past the cessation of treatments although total herbaceous plant control was not achieved in either study.

After five growing seasons in Study 1, differences in total height of all longleaf pine between the HPC (1.0 m tall) and NHPC (0.6 m tall) plots were apparent (Fig. 4). After three growing seasons in Study 2, I considered the differences in total height between the HPC (1.6 m tall) and NHPC (1.0 m tall) plots to be obvious. After 6 years, trees on the HPC and NHPC plots averaged 1.6 and 1.0 m tall, respectively, on Study 1, and on Study 2, trees on the HPC and NHPC plots averaged 4.8 and 3.9 m tall, respectively.

Woody plant control did not significantly affect longleaf pine height growth in either study (Table 1). However, the WPC treatment appeared to be effective because reducing the stature of the woody vegetation made the longleaf pine trees look taller than they were.

In both studies, HPC significantly increased height growth among the tallest 25% ($P = 0.0020$ in Study 1 and $P = 0.0009$ in Study 2) and middle 50%

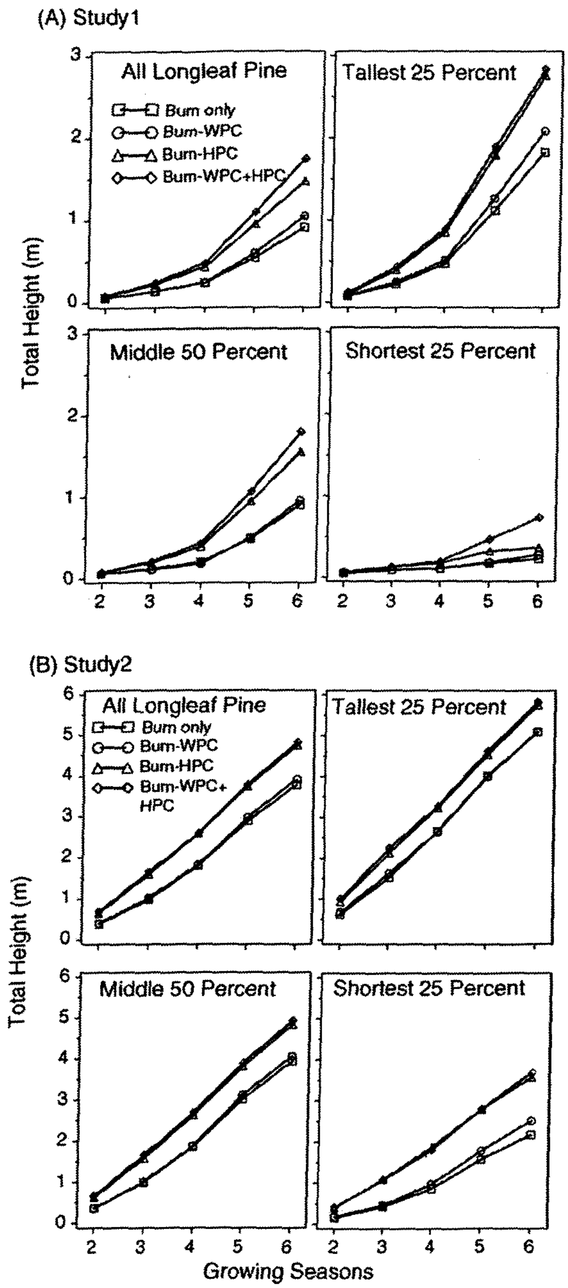

Fig. 4. Total height of all longleaf pine trees as well as the tallest 25%, middle 50%, and shortest 25% in two studies in central Louisiana by treatment combination: Burn only; Burn-woody plant control (WPC); Burn-herbaceous plant control (HPC); and Burn-WPC + HPC.

($P = 0.0013$ in Study 1 and $P = 0.0003$ in Study 2) of the longleaf pine trees (Fig. 4). There were also significant stand-age effects and AGE–HPC interactions in both studies. Therefore, the pattern of longleaf pine responses to treatments was similar for all longleaf pines, the tallest 25%, and the middle 50% of the population. Thus, a time-of-emergence-from-the-grass-stage effect was not evident as originally proposed.

In Study 1, the shortest 25% of the longleaf pines on Burn-WPC–HPC plots (0.7 m) were taller than on the other three treatment combinations (average of 0.3 m), but there was not a significant WPC–HPC or AGE–WPC–HPC interaction (Fig. 4). In Study 2, the pattern of height growth for the shortest longleaf pine trees was similar to the pattern for all longleaf pines and the other two subpopulations (Fig. 4).

3.4. Understory vegetation

In Study 1, stand age and an AGE–HPC interaction significantly affected herbaceous plant cover (Table 1). After two growing seasons, the HPC plots averaged 55% herbaceous plant cover and the NHPC plots averaged 85% cover (Fig. 5). Herbicides were not applied in the third growing season, and

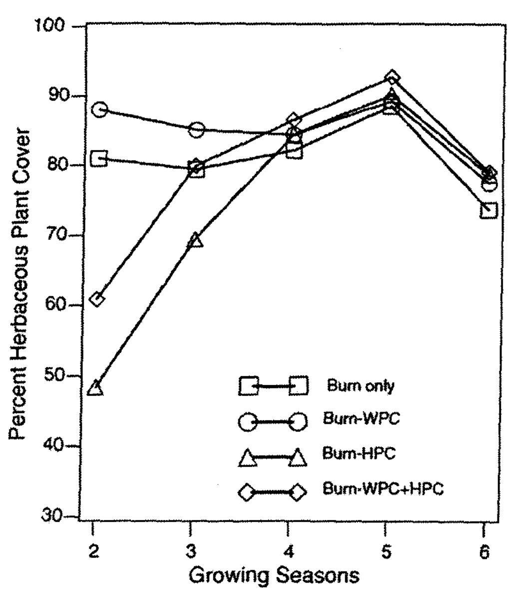

Fig. 5. In Study 1, percent herbaceous plant cover by treatment combination: burn only; burn-woody plant control (WPC); burn-herbaceous plant control (HPC); and burn-WPC + HPC.

Table 2
In both studies: (A) ovendried mass of vegetation in June of the first growing season and (B) degrees of freedom, probabilities of a greater F-value, and error mean squares from the analyses of variance

Variable values/analysis sources	d.f.	Study 1			Study 2		
		Herbaceous plants (kg/ha)	Arborescent plants and vines (kg/ha)	All competing vegetation (kg/ha)	Herbaceous plants (kg/ha)	Arborescent plants and vines (kg/ha)	All competing vegetation (kg/ha)
(A) Treatments							
Burn only		2058	349	2407	1055	263	1318
Burn-HPC[a]		1866	452	2318	2925	1015	3940
Burn-WPC[b]		1902	14	1917	2594	699	3293
Burn-WPC + HPC		1747	65	1812	678		
Analysis source	d.f.	$P > F$-values					
(B) Degrees of freedom, probabilities of greater F-values and error mean squares							
Block effect	3	0.7229	0.5583	0.3008	0.7168	0.4746	0.3810
HPC	1	0.3433	0.6210	0.6321	0.9800	0.5739	0.8455
WPC	1	0.4491	0.0404	0.0310	0.7035	0.6639	0.5427
WPC × HPC interactions	1	0.9181	0.8675	0.9702	0.0649	0.0946	0.0113s
Error mean square	9	120809.224	90851.169	152183.412	3242433.83	376284.319	2414564.48

[a] HPC—herbaceous plant control.
[b] WPC—woody plant control.

herbaceous plant cover increased to 75% on the HPC plots and remained at 82% on the NHPC plots. Thereafter, herbaceous plant cover was similar among all treatment combinations and averaged 84% from fourth to sixth growing seasons.

In general, the prescribed burn in the second growing season across Study 1 consumed most of the living herbaceous vegetation and litter; by fall, regrowth averaged 70% cover (Fig. 5). I did not burn or apply herbicides in the third year, but the severe to extreme growing-season drought conditions (Fig. 1) kept herbaceous plant growth in check. Herbaceous plant cover averaged 79% that fall. In the fourth growing season, I prescribed burned in April and drought conditions developed in May; so, herbaceous plant regrowth averaged 85% cover that fall. Drought conditions were mild to moderate in the fifth growing season with no burning. By that fall, herbaceous plant cover averaged 90% because the previous prescribed burn destroyed the litter and thereby favored grass production through the fifth growing season (Duvall, 1962; Grelen and Epps, 1967). The sixth growing season burn was intense enough to kill some of the longleaf pine trees (Fig. 2), and herbaceous plant cover averaged 77% that fall.

In Study 1, bluestem grasses dominated in the first growing season. Living herbaceous vegetation averaged 1893 kg (ovendried mass)/ha with no significant differences among treatments (Table 2). The lack of response on the HPC plots occurred because sethoxydim does not kill these dominant grasses; rather, it stunts their growth. Hexazinone at the rate used is effective against many forbs and some grasses but will not control bluestem (Haywood, 2000). In addition, only half of the plot surface was banded with herbicides; grasses in the untreated strips were free-to-grow.

Woody plant control significantly reduced woody plant productivity in the first growing season to 40 kg/ha compared to 400 kg/ha on the NWPC plots in Study 1 (Table 2). Because WPC reduced woody plant productivity, total plant productivity was also significantly less on the WPC plots (1864 kg/ha) than on the NWPC plots (2363 kg/ha). However, the woody vegetation was small in stature.

By the fourth growing season, total herbaceous plant productivity was significantly greater on the HPC plots (8024 kg/ha) than on the NHPC plots (6440 kg/ha) in Study 1 (Table 3). Grasses still dominated and covered 50% of the soil surface while forb cover averaged 29%. Arborescent vegetation averaged 17753 stems/ha, 0.12 m tall, and a crown width of 0.06 m across all treatments (Table 4). Herbaceous plant control tended to increase arborescent plant height ($P = 0.06$) and crown width

Table 3
(A) preburn ovendried mass of herbaceous plants in April 2001 (Study 1) and April 2000 (Study 2) and percent cover of herbaceous vegetation by taxa in August 2001 (for both studies), and (B) degrees of freedom, probabilities of a greater F-value, and error mean squares from the analyses of variance

Variable values/analysis sources		Study 1				Study 2			
		Herbaceous mass (kg/ha)	Grass cover (%)[b]	Forb cover (%)	Total cover (%)[c]	Herbaceous mass (kg/ha)	Grass cover (%)	Forb cover (%)	Total cover[b] (%)
(A) Treatment									
Burn only		6574	44	26	79	1908	38	14	52
Burn-HPC[a]		7961	50	28	87	1020	29	12	42
Burn-WPC[a]		6305	48	32	89	2657	47	25	73
Burn-WPC + HPC		8088	60	31	95	1533	37	32	69
Analysis source	d.f.	$P > F$-values							
(B) Degrees of freedom, probabilities of greater F-values and error mean squares									
Block effect	3	0.0019	0.0636	0.5434	0.0418	0.0158	0.2104	0.1604	0.0566
HPC	1	0.0010	0.1674	0.8945	0.0313	0.0009	0.1486	0.7620	0.3205
WPC	1	0.8339	0.2553	0.5742	0.0474	0.0140	0.2222	0.0177	0.0040
WPC × HPC	1	0.5629	0.6746	0.7792	0.9413	0.5832	0.9752	0.5038	0.6625
Error mean square	9	436955.14	0.01476	0.02243	0.01597	171974.56	0.01775	0.01764	0.02020

[a] HPC: herbaceous plant control and WPC: woody plant control.
[b] Percentages were arcsine transformed into radians before analysis.
[c] Total cover includes grasses, grass-like plants, forbs, and ferns.

($P = 0.06$), probably because HPC released some of the woody plants as well as the longleaf pine seedlings. The number of vines averaged 5864 stems/ha across all treatments with no significant differences between treatment levels.

In Study 2, HPC and an AGE–HPC interaction significantly affected herbaceous plant cover (Table 1). After the second year, herbaceous plant cover averaged 28% on the HPC plots and 67% on the NHPC plots. However, after three growing seasons,

Table 4
In both studies: (A) stocking, height, and width of arborescent vegetation and stocking of vines in August of the fourth growing season and (B) degrees of freedom, probabilities of a greater F-value, and error mean squares from the analyses of variance

Variable values/analysis sources		Study 1				Study 2			
		Arborescent vegetation			Vines	Arborescent vegetation			Vines
		Stocking[b] (stems/ha)	Total Height (m)	Crown width (m)	Stocking[b] (stems/ha)	Stocking[b] (stems/ha)	Total height (m)	Crown width (m)	Stocking[b] (stems/ha)
(A) Treatments									
Burn only		18031	0.06	0.03	4435	29270	0.59	0.31	8373
Burn-HPC[a]		21242	0.14	0.07	5917	33716	0.80	0.37	10897
Burn-WPC[a]		17537	0.12	0.06	4478	17661	0.27	0.16	4091
Burn-WPC + HPC		14203	0.14	0.07	8627	18031	0.34	0.19	14944
Analysis source	d.f.	$P > F$-values							
(B) Degrees of freedom, probabilities of greater F-values and error mean squares									
Block effect	3	0.0215	0.0218	0.0250	0.4158	0.0006	0.0150	0.0036	0.0697
HPC	1	0.5944	0.0608	0.0608	0.5361	0.9236	0.1450	0.2743	0.4665
WPC	1	0.2523	0.2966	0.2555	0.8770	0.0024	0.0017	0.0027	0.1675
WPC × HPC	1	0.8259	0.3081	0.4300	0.8393	0.5120	0.4396	0.6733	0.8283
Error mean square	9	0.8239	0.002436	0.0006054	0.9767	0.1361	0.03176	0.006499	0.9468

[a] HPC: herbaceous plant control and WPC: woody plant control.
[b] Stocking means were logarithmically transformed (log(Y)) before the analysis to equalize variances.

herbaceous plant cover increased on the HPC plots to 40% and decreased to 58% on the NHPC plots.

Treatments did not significantly affect herbaceous plant biomass in the first growing season in Study 2 (Table 2), and forbs were the dominant vegetation. Total herbaceous productivity was significantly less in the third growing season on the HPC plots (average of 1276 kg/ha) than on the NHPC plots (average of 2282 kg/ha) (Table 3). Woody plant control significantly increased herbaceous productivity, averaging 2095 kg/ha on the WPC plots and 1464 kg/ha on the no WPC (NWPC) plots.

Herbaceous productivity was now in a predictable pattern; HPC reduced productivity but was far from 100% effective because hexazinone was applied only to half the surface area and hexazinone does not control many of the plant species in Study 2 (Haywood, 2000). Grasses eventually became the dominant taxon covering 38% of the soil surface after 4 years across all treatments (Table 3). The WPC plots had significantly greater forb cover (29%) than the NWPC plots (13%), and forb cover averaged 21% across all treatments. Total cover was also significantly greater on the WPC plots (71%) than on the NWPC plots (47%), mostly because of the greater forb cover.

There was a significant WPC–HPC interaction in total understory vegetation productivity in the first growing season in Study 2 (Table 2). Treating only the woody or herbaceous plants caused the untreated vegetation to increase in productivity. On the HPC plots, the herbaceous vegetation that was not controlled responded to release, as did the woody vegetation. On the WPC plots, herbaceous vegetation responded to release. When both the herbaceous and woody vegetation were treated, productivity of vegetation was less, and treating none of the vegetation kept competitive pressure on all of the vegetation and yields were less.

By the fourth growing season in Study 2, WPC significantly reduced the stocking of arborescent vegetation from 31493 to 17846 stems/ha on the NWPC and WPC plots, respectively (Table 4). Likewise, plants were smaller in stature on the WPC plots (0.30 m tall and 0.17 m in width) than on the NWPC plots (0.70 m tall and 0.34 m in width). The number of vines averaged 9576 stems/ha across all treatments with no significant differences between treatment levels.

Although WPC reduced the number and stature of the recovering vegetation, it was not a fully successful control method. HPC did not affect arborescent vegetation development in Study 2, although it marginally affected development in Study 1 (Table 4). However, Study 1 (7232 kg/ha) had four times more herbage production than Study 2 (1780 kg/ha), and the competitive pressure in Study 2 from herbaceous plants was evidently less (Table 3).

3.5. Foliar nutrients

In Study 1, HPC reduced the sixth growing season percentage of C and concentration of Mg in the longleaf pine foliage, with C averaging 50.4 and 50.7% and Mg averaging 1.1 and 1.2 g/kg on the HPC and NHPC plots, respectively (Table 5). There was a WPC–HPC interaction in which HPC reduced the percentage of N but not if WPC was also applied. WPC applied alone did not affect percent N. Treatments did not significantly affect the foliar concentrations of P, K, and Ca.

In Study 2, HPC reduced the concentrations of Ca and Mg, with Ca averaging 1.6 and 1.9 g/kg and Mg averaging 0.8 and 0.9 g/kg on the HPC and NHPC plots, respectively (Table 5). Treatments did not significantly affect the percentages of foliar C and N or the concentration of K.

Based on Blevins et al., 1996, the concentration of P was below the sufficiency level of 0.8 g/kg for longleaf pine foliage on both studies, except for the WPC–HPC plots in Study 1 (Table 5). This was expected because the soils in both studies are generally deficient in P for growing pine trees (Tiarks, 1983; Burton, 1984; Haywood and Tiarks, 1990; Haywood et al., 2003). The foliar concentrations of K, Ca, and Mg were above the sufficiency levels of 3.0, 1.0 and 0.6 g/kg, respectively, across both studies (Blevins et al., 1996). Foliar N was above the sufficiency level of 0.95% in Study 1 but not in Study 2.

4. Silvicultural implications

Despite drought conditions, the survival of longleaf pine seedlings was acceptable, averaging 73% after the first growing season across both studies with no precipitant loss of seedlings after the

Table 5
In both studies: (A) percent C and N and concentrations of P, K, Ca, and Mg in the longleaf pine foliage after six growing seasons and (B) degrees of freedom, probabilities of a greater F value, and error mean square from the analyses of variance

		C (%)	N (%)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)
(A) Study and treatments							
Study 1: treatments							
Burn only		50.8	1.07	0.66	4.04	2.34	1.22
Burn-HPC[a]		50.4	0.98	0.66	4.63	2.00	1.05
Burn-WPC[a]		50.7	1.02	0.70	4.46	2.21	1.22
Burn-WPC + HPC		50.4	1.07	0.86	4.47	2.15	1.15
Study 2: treatments							
Burn only		50.6	0.89	0.72	5.76	1.78	0.91
Burn-HPC[a]		50.6	0.86	0.66	5.60	1.61	0.82
Burn-WPC[a]		50.5	0.88	0.69	6.01	1.98	0.92
Burn-WPC+HPC		50.6	0.88	0.69	6.02	1.60	0.84
Analysis sources	d.f.	$P > F$-value[b]					
(B) Degrees of freedom, probabilities of a greater F-value, and error mean square							
Study 1							
Block	3	0.4026	0.0578	0.8086	0.1820	0.5633	0.0476
HPC	1	0.0379	0.4326	0.3556	0.1588	0.1558	0.0502
WPC	1	0.8248	0.4381	0.1625	0.5044	0.8927	0.3840
WPC × HPC[a]	1	0.6725	0.0289	0.3805	0.1741	0.3161	0.2885
EMS[a]	9	0.00000693	0.00000667	0.03495	0.008392	0.01533	0.009821
Study 2							
Block	3	0.3697	0.0005	0.0079	0.0018	0.0530	0.0030
HPC	1	0.6975	0.6384	0.3323	0.7195	0.0182	0.0041
WPC	1	0.6612	0.8013	0.8908	0.1221	0.3137	0.7641
WPC × HPC[a]	1	0.8800	0.7130	0.2405	0.7542	0.3347	0.7770
EMS[a]	9	0.00001492	0.00000776	0.005188	0.005697	0.01090	0.002655

[a] HPC: herbaceous plant control and WPC woody plant control, WPC × HPC the interaction of the two treatments, and EMS: error mean square.
[b] Nutritional concentrations were logarithmically transformed and percentages were arcsine transformed into radians before analysis.

first year. I credited the better-than-expected survival rate to using longleaf pine container stock of good quality and proper planting practices. Barnett (2002) recommends planting container stock over bareroot seedlings to ensure better survival under adverse conditions.

Longleaf pine seedlings emerged early from the grass stage at Study 2 regardless of treatment (Fig. 3). In fact, longleaf pines in Study 2 were as tall after three growing seasons as the longleaf pine in Study 1 were after six growing seasons. I partly attributed the growth rate in Study 2 to less herbaceous cover because herbaceous vegetation was most responsible for keeping longleaf pine growth in check in both studies. Likewise Brockway and Outcalt (2000) increased development of longleaf pine seedlings by applying hexazinone herbicide to grass dominated cover on a prescribed burned site.

Inherent site quality likely influenced growth rates in both studies as well, but differences in the intensity of the prescribed burns may have also been a factor because the grass-dominated fuels at Study 1 carried three intense prescribed burns across the site likely and adversely affecting seedling growth as found by Haywood (2002) in another study. At Study 2, there was less herbaceous plant biomass than at Study 1 with many erect forbs in the herbaceous community. This non-uniform, vertical fuel bed kept fire intensities low; in addition, only two burns were completed in Study 2.

Brown-spot needle blight can keep longleaf pine seedlings in the grass stage and nullify treatment effects (Derr, 1957), but I did not have a disease problem. Low disease incidence probably contributed to the timely initiation of height growth on all treatments (Kais et al., 1986) as well as the strong response to HPC in both studies.

The HPC treatment resulted in rapid establishment of the longleaf pine trees in both studies despite the adverse climatic conditions in the first three growing seasons although total control of herbaceous plants was not achieved. Controlling woody vegetation allowed aesthetically pleasing pine grasslands to develop, but the WPC treatment did not affect longleaf pine growth. A lack of response to the WPC treatment was understandable in Study 1 where the fires were intense and the combination of burning and herbaceous plant competition may have kept the arborescent vegetation in check (Table 4). However, in Study 2, the fires were less intense and woody plants were the dominant understory vegetation.

Although controlling woody plants was not beneficial in terms of longleaf pine seedling development, it may be necessary to keep arborescent vegetation in check long enough for fuel conditions to reach a stage where more intense fires are possible on sites such as Study 2. If arborescent vegetation develops unchecked in young longleaf pine plantations, an eventual return to mixed pine-hardwood forest cover will be the likely outcome (Haywood and Grelen, 2000; Haywood et al., 2001) because loblolly pine and hardwood brush will outgrow many of the longleaf pine seedlings (Haywood, 2000).

However, some land managers may be willing to allow brush encroachment on sites where intense prescribed burns are not achieved during stand establishment with the opinion that by the time canopy closure is reached needle cast will improve fuel bed conditions and more intense fires will be possible. After stand closure, continual burning coupled with a chemical or mechanical hardwood release treatment may create the kind of open stand conditions that have proved difficult to achieve on Study 2 using early intervention practices. If land managers focus on crop trees and not on the overall population of trees, the growth rate of the tallest 25% of the longleaf pine trees without either HPC or WPC treatments suggests that a less intense management approach may work in the long term (Fig. 4). Nevertheless, it is likely that where vegetation components have shifted away from the historical pine-grassland type, such as Study 2, an aggressive burning program applied over several decades will be necessary to eventually decrease the number and stature of woody plants and favor herbaceous vegetation (Waldrop et al., 1992).

Percentage of foliar N was sufficient on Study 1, and it was only marginally deficient at Study 2 (Blevins et al., 1996). Foliar P concentration was generally deficient in both studies, but the average foliar concentration of 0.70 g/kg was close to the sufficiency level of 0.8 g/kg (Blevins et al., 1996). Foliar K, Ca, and Mg concentrations were above their sufficiency levels in both studies. Apparently, the HPC and WPC treatments did not adversely affect nutrient levels in the longleaf pine foliage on these moderately textured soils.

References

Barnett, J.P., 1989. Site preparation, containers, and soil types affect field performance of loblolly and longleaf pine seedlings. Proc. Bienn. South. Silvic. Res. Conf. 5, 155–158.

Barnett, J.P., 2002. Longleaf pine: why plant it? Why use containers? in: Barnett, J.P., Dumroese, R.K., Moorhead, D.J. (Eds.), Proceedings of Workshops on Growing Longleaf Pine in Containers—1999 and 2001. USDA For. Serv. South. Res. Stn. Gen. Tech. Re SRS-56, Asheville, NC, pp. 5–7.

Blevins, D., Allen, H.L., Colbert, S., Gardner, W., 1996. Nutrition management for longleaf pinestraw. Woodland Owners Notes no. 30, NC State University, North Carolina Cooperative Extension Service, Raleigh, NC.

Boyer, W.D., 1989. Response of planted longleaf pine bare-root and container stock to site preparation and release: fifth-year results. Proc. Bienn. South. Silvic. Res. Conf. 5, 165–168.

Boyer, W.D., 1993. Long-term development of regeneration under longleaf pine seedtree and shelterwood stands. South. J. Appl. For. 17, 10–15.

Brockway, D.G., Outcalt, K.W., 1998. Gap-phase regeneration in longleaf pine wiregrass ecosystems. For. Ecol. Manage. 106, 125–139.

Brockway, D.G., Outcalt, K.W., 2000. Restoring longleaf pine wiregrass ecosystems: hexazinone application enhances effects of prescribed fire. For. Ecol. Manage. 137, 121–138.

Burton, J.D., 1984. A continuous function approach to measuring response of young pine plantations to rates of application of nitrogen and phosphorus fertilizers. II. Longleaf pine on Ruston and Lucy soils. Establishment Report FS-S0-1102-7.10. USDA For. Serv. South. For. Exp. Stn., Pineville, LA.

Cordell, C.E., Anderson, R.L., Kais, A.G., 1989. How to identify and control brown-spot disease on longleaf pine. USDA For. Serv., South. Region Protection Report R8-PR 15, Atlanta, GA.

Croker Jr., T.C., Boyer, W.D., 1975. Regenerating longleaf pine naturally. USDA For. Serv. South. For. Exp. Stn. Res. Pa SO-105, New Orleans, LA.

Derr, H.J., 1957. Effects of site treatment, fertilization, and brown-spot control on planted longleaf pine. J. For. 55, 364–367.

Duvall, V.L., 1962. Burning and grazing increase herbage on slender bluestem range. J. Range Manage. 15, 14–16.

Grelen, H.E., Epps Jr., E.A., 1967. Herbage responses to fire and litter removal on southern bluestem range. J. Range Manage. 20, 403–404.

Harlow, W.M., Harrar, E.S., 1969. Textbook of Dendrology. McGraw-Hill Book Co., New York, pp. 81–84.

Haywood, J.D., 2000. Mulch and hexazinone herbicide shorten the time longleaf pine seedlings are in the grass stage and increase height growth. New For. 19, 279–290.

Haywood, J.D., 2002. Delayed prescribed burning in a seedling and sapling longleaf pine plantation in Louisiana. Proc. Bienn. South. Silvic. Res. Conf. 11, 103–108.

Haywood, J.D., Grelen, H.E., 2000. Twenty years of prescribed burning influence the development of direct-seeded longleaf pine on a wet pine site in Louisiana. South. J. Appl. For. 24, 86–92.

Haywood, J.D., Tiarks, A.E., 1990. Eleventh-year results of fertilization, herbaceous, and woody plant control in a loblolly pine plantation. South. J. Appl. For. 14, 173–177.

Haywood, J.D., Goelz, J.C., Sword Sayer, M.A., Tiarks, A.E., 2003. Influence of fertilization, weed control, and pine litter on loblolly pine growth and productivity and understory plant development through 12 growing seasons. Can. J. For. Res. 33, 1974–1982.

Haywood, J.D., Harris, F.L., Grelen, H.E., 2001. Vegetative response to 37 years of seasonal burning on a Louisiana longleaf pine site. South. J. Appl. For. 25, 122–130.

Kais, A.G., Cordell, C.E., Affeltranger, C.E., 1986. Benomyl root treatment controls brown-spot disease on longleaf pine in the southern United States. For. Sci. 32, 506–511.

Kerr Jr., A., Griffis B.J., Powell J.W., Edwards J.P., Venson R.L., Long J.K. Kilpatrick W.W., 1980. Soil survey of Rapides Parish, Louisiana. USDA Soil Conserv. Serv. and For. Serv. in cooperation with Louisiana State University, Louisiana Agric. Exp. Stn., Baton Rouge, LA.

Kush, J.S., Meldahl, R.S., Boyer, W.D., 1999. Understory plant community response after 23 years of hardwood control treatments in natural longleaf pine (*Pinus palustris*) forests. Can J. For. Res. 29, 1047–1054.

Louisiana Office of State Climatology, 2002. Louisiana monthly climate review. Southern Regional Climate Center, Department of Geography and Anthropology, Louisiana State University 22, Baton Rouge, LA.

Loveless, R.W., Pait III, J.A., McElwain, T., 1989. Response of longleaf pine to varying intensity of silvicultural treatments. Proc. Bienn. South. Silvic. Res. Conf. 5, 159–164.

McNab, W.H., Avers, P.E. (comps), 1994. Ecological subregions of the United States: section descriptions USDA For. Serv.. Washington Off. Admin. Pub. WO-WSA-5, Washington, DC.

National Climatic Data Center, 2004. NCDC: CLIMVIS inventory, http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgrg2.html. Climate Services Branch, National Climatic Data Center, 150 Patton Avenue, Asheville NC 28801-5001.

Nelson, L.R., Zutter, B.R., Gjerstad, D.H., 1985. Planted longleaf pine seedlings respond to herbaceous weed control using herbicides. South. J. Appl. For. 9, 236–240.

Palik, B.J., Mitchell, R.J., Houseal, G., Pederson, N., 1997. Effects of canopy structure on resource availability and seedling responses in a longleaf pine ecosystem. Can. J. For. Res. 27, 1458–1464.

Ramsey, C.L., Jose, S., Brecke, B.J., Merritt, S., 2003. Growth response of longleaf pine (*Pinus palustris* Mill.) seedlings to fertilization and herbaceous weed control in an old field in southern USA. For. Ecol. Manage. 172, 281–289.

Ross, W.G., Kulhavy, D.L., Conner, R.N., 1997. Stand conditions and tree characteristics affect quality of longleaf pine for red-cockaded woodpecker cavity trees. For. Ecol. Manage. 91, 145–154.

SAS Institute Inc., 1985. SAS User's Guide: Statistics. fifth ed. SAS Institute Inc., Cary, NC.

Steel, R.G.D., Torrie, J.H., 1980. Principles and procedures of statistics a biometrical approach., second ed. McGraw-Hill Book Company, New York.

Tiarks, A.E., 1983. Effects of site preparation and fertilization on slash pine growing on a good site. Proc. Bienn. South. Silvic. Res. Conf. 2, 34–39.

Turner, R.L., Van Kley, J.E., Smith, L.S., Evans, R.E., 1999. Ecological classification system for the national forests and adjacent areas of the West Gulf Coastal Plain. The Nature Conservancy, Nacogdoches, TX.

Wahlenberg, W.G., 1946. Longleaf pine its use, ecology, regeneration, protection, growth, and management. Charles Lathrop Pack Forestry Foundation and USDA For. Serv., Washington, DC.

Waldrop, T.A., White, D.L., Jones, S.M., 1992. Fire regimes for pine-grassland communities in the southeastern United States. For. Ecol. Manage. 47, 195–210.