Pine Straw Harvesting, Fire, and Fertilization Affect Understory Vegetation within a Louisiana Longleaf Pine Stand

James D. Haywood

ABSTRACT

Pine straw harvesting can provide an economic benefit to landowners, but the practice may also change the composition of plant communities. This research was initiated in a 34-year-old stand of longleaf pine (*Pinus palustris* Mill.) established in 1956 to study how pine straw management practices (fertilization, prescribed fire, and straw harvesting) affected plant communities, and herein, effects on understory vegetation are reported. A randomized complete block split-plot design was installed with two main plots: (1) no fertilization and (2) fertilization three times with different combinations of N, P, and K. There were four subplot treatments: (1) control, (2) prescribed fire, (3) prescribed fire and 2 harvests of pine straw, and (4) 13 annual harvests of pine straw. Fertilization significantly increased grass cover as a percentage of surface area. However, there was a general lack of understory plant response to nutrient amendments, partly because pine straw harvesting and burning were confounding fertilization effects. Prescribed fire and mechanical harvesting activities created similar understories on subplot treatments 2, 3, and 4 by significantly reducing understory woody plant stature and removing litter. Increases in understory tree and shrub stature, number of woody vines per acre, and percentage of woody plant cover significantly decreased herbaceous plant yields and percentage of cover.

Keywords: diammonium phosphate, *Pinus palustris* Mill., potash, triple superphosphate, understory plant community

Pine straw, a renewable natural resource, has traditionally been harvested for mulch (Jemison 1943, Bateman and Wilson 1961, Makus et al. 1994). Longleaf pine (*Pinus palustris* Mill.) straw is considered to be one of the best sources of landscape mulch among the southern pines (Mississippi State University 2011) and can bring a higher price per bale than pine straw bales from other southern pine species (Dickens et al. 2011). Adding pine straw to timber and forage as products of management can increase profits substantially, and the income from multiple straw harvests may exceed that from timber sales (Roise et al. 1991).

Pine straw yields from longleaf pine stands of at least 80 ft^2/ac of basal area can be expected to exceed 2,200 lb/ac, and at 120 ft^2/ac of basal area, stands on the best sites can be expected to produce over 4,000 lb/ac of pine straw on a dry weight basis (Blevins et al. 1996/2005). At these levels of production, it might be possible for landowners with longleaf pine stands in good locations and with proper management to make $30 to over $150 per acre per year of harvest by allowing pine straw producers to collect the fallen needles (e.g., Hayes et al. 2011, Mississippi State University 2011, Texas A&M University 2011).

Despite the immediate economic benefits, repeated removal of the forest floor may adversely affect pine tree growth (Jemison 1943, Lutz and Chandler 1946, Ginter et al. 1979). Fertilization is often recommended where pine straw is being harvested as a way to replace nutrients removed in the straw (Morris et al. 1992, Blevins et al. 1996/2005, Dickens et al. 2011).

When the research reported on here was initiated in 1990, pine straw management practices in the West Gulf Coastal Plain included fertilization, mechanical vegetation control to help improve access to the straw, prescribed fire to assist in clearing litter and debris, and the harvesting of the fallen needles (Henry Pearson, pers. comm., US Forest Service, Southern Forest Experiment Station, May 15, 1990). No formal studies were under way in the West Gulf to study these pine straw management practices at the time, and the US Forest Service was interested in studying this activity as a way of supporting the pine straw industry and determining the effects of pine straw harvesting within longleaf pine stands. Therefore, pine straw management practices were initiated in a 34-year-old stand of longleaf pine that originated from direct seeding in 1956. Herein, the objectives were to determine how these pine straw management practices influenced understory vegetation and the relationships between herbaceous and woody plant cover over a 14-year period.

Methods

Study Site Description

In 1954, 75% of the commercial forestland in central and southwestern Louisiana and East Texas was either barren of trees or supported understocked stands of pines and low-value hardwoods (Cassady and Mann 1954). Livestock grazing on these lands was mostly conducted on the free range principle, but unregulated management led to poor-quality cattle herds (Cassady and Mann 1954, Duvall 1964). It was under these conditions that the Longleaf Tract of the Palustris Experimental Forest was established in 1950 on the Kisatchie National Forest in central Louisiana (approximately 92° 30′W, 31°N at 160 ft above sea level) to promote the study of range science as a way to improve cattle management in the South. Duvall (1962) described vegetation in the grass savannas that covered most of the Longleaf Tract. He reported that grasses constituted 90% of

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James D. Haywood (dhaywood@fs.fed.us), US Forest Service, Southern Research Station, Alexandria Forestry Center, 2500 Shreveport Highway, Pineville, LA 71360.

the herbaceous plant cover, principally slender little bluestem (*Schizachyrium tenerum* Nees) with less little bluestem (*Schizachyrium scoparium* [Michx.] Nash var. *divergens* [Hack.] Gould). Other typical grasses were panic grasses (*Panicum* spp.), paspalums (*Paspalum* spp.), Elliott's bluestem (*Andropogon gyrans* Ashe var. *gyrans*), splitbeard bluestem (*Andropogon ternarius* Michx.), big bluestem (*Andropogon gerardii* Vitman), and common carpetgrass (*Axonopus fissifolius* [Raddi] Kuhlm.).

The 250-ac study site on the Longleaf Tract is gently rolling Ruston (fine-loamy, siliceous, semiactive, thermic Typic Paleudults) and Smithdale (fine-loamy, siliceous, subactive, thermic Typic Hapludults) fine sandy loam soils with slopes varying from 1 to 8% (Kerr et al. 1980). The longleaf pine stand originated from direct seeding in 1956 and was 34 years old from seed in 1990. The site had been repeatedly prescribed burned on a 3-year interval as part of the range management program, which suppressed development of understory woody vegetation (Duvall 1962). The entire site was last burned in 1987 before study initiation. The longleaf pine stand had a site index of 86 ft at age 50 years.

During this study from 1990 through 2004, mean January and July temperatures were 50°F and 83°F, respectively, in central Louisiana (National Climatic Data Center 2011). Annual precipitation averaged 59 in., and growing season precipitation (March through November) averaged 44 in./year. August was the driest month on average (3.5 in./year), and January was the wettest month on average (7.1 in./year).

The research plots were thinned in June 1999 for red-cockaded woodpecker (*Picoides borealis*) habitat management, in which pine stands are typically maintained at 50–80 ft^2/ac (US Fish and Wildlife Service 2008) with a target basal area of 65 ft^2/ac. Prior to thinning, the subplot basal area ranged from 103 to 111 ft^2/ac and averaged 107 ft^2/ac. The subplots were thinned to a residual basal area of 62 to 66 ft^2/ac and averaged 64 ft^2/ac.

Treatment Establishment

In 1990, four 3.2-ac research blocks were installed in the 34-year-old longleaf pine stand as a randomized complete block split-plot design with two main plots and four subplots per block. Blocking was based on initial overstory basal area. Each square subplot was 0.39-ac with an interior 0.23-ac measurement area. In August 1990, understory vegetation was rotary mowed to create uniform understory conditions on all 32 subplots.

The two main plot treatments were (1) no fertilization and (2) fertilization. The fertilized plots were treated in April 1991 and May 1997 with 45 lb N and 50 lb P/ac broadcast evenly over the main plot as 250 lb/ac diammonium phosphate (DAP). In April 2004, plots were treated with 50 lb P and 72 lb K/ac as 250 lb/ac triple superphosphate (TSP) and 250 lb/ac potash, respectively.

The four subplot treatments were control (C), prescribed burned (PB), prescribed burned and two pine straw harvests (PBH), and annual straw harvests (AH). On the C subplots, no prescribed burning was done after 1987 or rotary mowing after 1990. The PB subplots were burned in March 1991, February 1994, March 1997, January 2000, June 2002, and May 2004. The PBH subplots were burned along with the PB subplots, and the pine straw was harvested in early 1992 and 1993. The AH subplots were prescribed burned in August 1991, rather than March 1991, and the pine straw was harvested 13 times from early 1992 through April 2006.

Pine straw harvesting was conducted as follows. The PBH and AH subplots were rotary mowed in July 1991. After needle fall peaked from September through December (Haywood et al. 1996), the litter was collected in windrows with a tractor mounted straight-bar rake. Large limbs and cones were removed. The straw was mechanically baled in early 1992 and removed from the site. The PBH and AH subplots were again rotary mowed in July 1992 and the straw harvested in early 1993.

To address the effects of short-term pine straw harvesting as compared with long-term harvesting, straw removal on the PBH subplots stopped after two annual harvests (Haywood et al. 1998). However, straw harvesting continued on the AH subplots with rotary mowing in July 1993 through 1997 and straw harvesting in April 1994, January 1995, February 1996, April 1997, and April 1998. The mineral soil was eventually left bare on much of the harvested surface of the AH subplots until new needle fall and herbaceous vegetation again covered the soil (Haywood et al. 1998). The loss of the forest floor is commonly observed after continual mechanical harvesting of pine straw.

Because all subplots were thinned in June 1999, pine straw was not harvested in 1999 on the AH subplots to allow a fuel bed to develop before the PB, PBH, and AH subplots were prescribed burned in January 2000. Straw harvesting resumed on the AH subplot treatment with rotary mowing in October 2000 and the pine straw being raked off the subplots in January 2001. Pine straw was again baled and removed from the site following the 9th through 11th and 13th harvests in January 2002, February 2003, January 2004, and April 2006. In April 2005, the pine straw was raked off the subplots and not baled because of equipment failure.

Understory Plant Sampling

In September 2002, five 0.25-milacre plots were systematically located on each 0.39-ac subplot for collecting herbaceous plant biomass samples and for measuring understory trees and shrubs (which included blackberry [*Rubus* spp.]) and woody vines. A 0.25-milacre plot was placed in the center of each quarter and in the middle of each 0.23-ac measurement area of the subplot, thus forming an X pattern. The herbaceous plants were clipped to groundline and divided into four taxa: grasses, grasslike plants, forbs, and ferns. The clipped samples were ovendried at 175°F for 72 hours in a forced-air oven to determine ovendried weight by taxon. Trees and shrubs with their pith in the 0.25-milacre plot at groundline were counted, and heights and crown widths were measured. Woody vines with stems originating in the 0.25-milacre plot were counted.

In September 2003 and 2004, five 1.0-milacre plots were overlain on the 0.25-milacre plots that had been established in September 2002. The five plots were inventoried to determine the percentage of understory plant cover divided among eight taxa: grasses, grasslike plants, forbs, ferns, trees, shrubs, blackberry, and woody vines. Additionally, in September 2004, trees and shrubs over 4.5 ft tall, excluding blackberry, were inventoried, and dbh and crown widths were measured on the five plots.

Data Analysis

For September 2002, main-plot and subplot treatment means for oven-dried weights of the four taxa of herbaceous plants, number of understory trees and shrubs per acre and their average height and crown width, and number of woody vines per acre were compared with a randomized complete block split-plot design model with SAS statistical software (SAS Institute, Inc., 1985). All main, subplot, and interaction effects were considered significant at a probability of a greater *F*-value (P) ≥ 0.05.

Table 1. In September 2002, understory production for four taxa of herbaceous plants, number of trees and shrubs per acre, their average height and crown width, and number of woody vines per acre.

		Herbaceous plants				Trees and shrubs			
Main plot and subplot treatments		Grasses	Grasslike plants	Forbs	Ferns	Stems per acre (count)	Average height	Average crown width	Vines per acre (count)
		(lb/ac)					(ft)		
No fertilizer									
C		41	5	56	55	9,800	2.1	1.2	9,200
PB		384	13	198	40	9,150	0.6	0.4	3,000
PBH		378	8	185	119	8,450	0.8	0.5	2,200
AH[a]		371	6	108	54	4,500	0.7	0.5	1,500
No fertilizer average		294	8	137	67	7,975	1.0	0.7	3,975
Twice fertilized[b]									
C		56	1	29	15	10,650	2.2	1.1	18,500
PB		299	3	171	315	14,650	0.9	0.6	1,900
PBH		273	12	123	161	8,450	0.6	0.4	1,350
AH		323	8	158	4	2,200	0.5	0.5	1,100
Fertilization average		238	6	120	124	8,988	1.1	0.7	5,713
Analysis of variance	df[c]				Probability >*F*-value				
Block	3	0.0420	0.9501	0.5921	0.6144	0.2261	0.0179	0.2265	0.7569
F	1	0.1459	0.6350	0.4834	0.2410	0.1388	0.5449	0.9963	0.8426
Main EMS[c]	3	6,506.87	110.602	3,418.70	12,154.0	0.02785	0.02025	0.04298	0.30559
ST	3	0.0008	0.3050	0.0156	0.0605	0.0026	<0.0001	0.0009	<0.0001
C versus (PB + PBH + AH)/3	1	<0.0001	0.0845	0.0028	0.1273	0.0765	<0.0001	<0.0001	<0.0001
PB versus (PBH + AH)/2	1	0.9291	0.9955	0.2601	0.0981	0.0037	0.7565	0.9696	0.4547
PBH versus AH	1	0.7587	0.4614	0.6146	0.0880	0.0221	0.7973	0.6885	0.5718
F × ST interactions	3	0.8298	0.2206	0.5763	0.0573	0.5023	0.7993	0.8965	0.3273
Subplot EMS	18	1,859.55	51.5155	6,564.46	15,165.3	0.47988	0.30624	0.11045	0.52060

C, control; PB, prescribed burn; PBH, prescribed burn and two harvests; AH, annual harvest; ST, subplot treatments; F, fertilization; df, degrees of freedom; EMS, error mean square.

[a] The pine straw was harvested nine times from 1992 through 2002.

[b] Fertilizer was evenly broadcast over the entire main plot at two times before September 2002: 45 lb N and 50 lb P/ac in April 1991 and in May 1997.

[c] Counts were logarithmically transformed before analysis.

For September 2003 and 2004, percentage of understory cover of the eight plant taxa were also compared with a randomized complete block split-plot design model. After the initial analyses, it became apparent that combining the taxa into three groups—grasses, all herbaceous plants, and woody plants—was the most efficient way to report results from the analyses. In addition, the number of understory trees and shrubs per acre over 4.5 ft tall and their average height and crown width measured in September 2004 were compared.

For all analyses of variance, orthogonal linear contrasts were used to compare subplot treatments: (1) control versus the mean for vegetation management (PB + PBH + AH)/3, (2) prescribed fire (PB) versus the mean for pine straw harvesting (PBH + AH)/2, and (3) two harvests (PBH) versus annual harvest (AH). Number of stems per acre was logarithmically transformed, and percentages were arcsine transformed before analysis (Steel and Torrie 1980).

Regression analyses were done to determine the relationship between herbaceous plant production in lb/ac (y) as predicted or estimated by number of understory trees and shrubs per acre and their average height and crown width or number of woody vines per acre (x values) in September 2002 with SAS statistical software (SAS Institute, Inc., 1985). Similarly, regression analyses were done to determine the relationship between percentage of cover of grasses or all herbaceous plants (y) as estimated by woody plant cover (x) in September 2003 and 2004.

Results

When this longleaf pine stand originated in 1956, grasses dominated the plant cover (Duvall 1962). Across the study site, grasses made up 54% of the total herbaceous plant biomass under the 46-year-old trees in September 2002 (Table 1). The application of DAP in 1991 and 1997 did not significantly affect yields of grasses, grasslike plants, forbs, or ferns. Likewise, the number of understory trees, shrubs, and woody vines per acre and the average height and crown width of trees and shrubs were not affected by application of DAP.

The use of prescribed fire and pine straw harvesting significantly affected herbaceous plant production. The PB, PBH, and AH subplots averaged significantly more grass (338 lb/ac) and forb (157 lb/ac) production than the C subplots, which had 49 lb/ac of grass and 43 lb/ac of forbs (Table 1). Conversely, understory trees and shrubs on the PB, PBH, and AH subplots were shorter, with smaller crown width, and there were fewer woody vines per acre than on the C subplots. The mechanical activity of the pine straw harvesting equipment on the PBH and AH subplots resulted in fewer trees and shrubs per acre than on the PB subplots, and annual harvesting of straw resulted in fewer trees and shrubs per acre than only harvesting the straw twice. The number of trees and shrubs per acre were ranked as 3,350, 8,450, and 11,900 plants per acre on the AH, PBH, and PB subplots, respectively.

Yields of grasslike plants were too low on all subplot treatments (an average of 7 lb/ac) to expect to find significant differences given the inherent variability associated with working across the 250-ac site (Table 1). However, fern yields averaged 96 lb/ac and ranged from 4 to 315 lb/ac across all eight fertilization-by-subplot treatment combinations. Although fertilization and subplot treatments appeared to have an interactive effect on fern production, the fertilization-by-subplot treatment interaction was not significant (P = 0.0573). Nevertheless, subplots that were repeatedly prescribed burned produced 159 lb/ac of ferns whereas C subplots produced 35 lb/ac of ferns.

Across all treatments in September 2003, grasses were 42% of the herbaceous plant cover and 26% of the herbaceous plus woody plant

Table 2. In September 2003 and 2004, percentage of understory cover for only grasses, all herbaceous plants including grasses, and woody plants.

Main plot and subplot treatments		September 2003			September 2004		
		Only grasses	All herbaceous plants	Woody plants	Only grasses	All herbaceous plants	Woody plants
		.(%)					
No fertilizer							
C		7	22	32	6	15	43
PB		21	47	14	15	33	9
PBH		22	52	17	18	43	9
AH[a]		29	42	9	29	37	8
Average		20	41	18	17	32	18
Thrice fertilized[b]							
C		2	8	69	2	5	69
PB		13	49	34	8	41	20
PBH		18	57	14	10	45	11
AH		22	41	6	24	40	4
Average		14	39	31	11	33	26
Analysis of variance	df[c]	Probability > F-value					
Block	3	0.0258	0.5814	0.4637	0.0816	0.4432	0.3182
F	1	0.0060	0.3543	0.1108	0.0268	0.7926	0.0372
Main EMS[c]	3	4.21622	27.2545	106.500	14.2803	17.6357	19.1956
ST	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
C versus (PB + PBH + AH)/3	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
PB versus (PBH + AH)/2	1	0.0267	0.8770	0.0228	0.0045	0.2842	0.0920
PBH versus AH	1	0.1302	0.0024	0.1012	<0.0001	0.2113	0.3250
F × ST interactions	3	0.8481	0.0142	0.0166	0.9383	0.0613	0.0666
Subplot EMS	18	21.8682	18.8030	72.3532	31.7204	24.4085	54.9192

C, control; PB, prescribed burn; PBH, prescribed burn and two harvests; AH, annual harvest; ST, subplot treatments; F, fertilization; df, degrees of freedom; EMS, error mean square.
[a] The pine straw was harvested 11 times from 1992 through 2004.
[b] Fertilizer was evenly broadcast over the entire main plot at three times: 45 lb N and 50 lb P/ac in April 1991 and May 1997 and with 50 lb P and 72 lb K/ac in April 2004.
[c] Percentages were arcsine transformed before analysis.

cover in the understory (Table 2). The application of DAP in 1991 and 1997 resulted in less grass cover (14%) than on the unfertilized plots (20%), but fertilization did not significantly affect woody plant cover. The PB, PBH, and AH subplots averaged significantly greater grass (21%) and total herbaceous plant cover (48%) than the C subplots that had 5% grass and 15% total herbaceous plant cover. Conversely, cover of woody plants was less on the PB, PBH, and AH subplots (16%) than on C subplots (50%).

Pine straw harvesting on the PBH and AH subplots resulted in significantly more grass cover (an average of 23%) than on PB subplots that had 17% grass cover in 2003 (Table 2). Woody plant cover was also less on the PBH and AH subplots (an average of 11%) than on the PB subplots (24%). Total herbaceous plant cover was less on AH subplots (42%) than on PBH subplots (55%).

Two significant fertilization-by-subplot treatment interactions occurred in September 2003 (Table 2). First, total herbaceous plant cover was 8% on the fertilized-C subplots but averaged 44% on the other seven fertilization-by-subplot treatment combinations. Second, woody plant cover was 17 and 9% on the unfertilized-PBH and -AH subplots, respectively; this was similar on the fertilized-PBH and -AH subplots, at 14 and 6%, respectively. However, the unfertilized-C and -PB subplots averaged 23% woody plant cover, compared with 51% average cover on the fertilized-C and -PB subplots. The significant interaction affecting woody plant cover might explain why there was not a significant fertilization effect influencing woody plant cover.

In September 2004, the PB, PBH, and AH subplots averaged greater grass (17%) and total herbaceous plant cover (40%) than the C subplots, which had 4% grass and 10% total herbaceous plant cover (Table 2). Average cover of woody plants was significantly less on the PB, PBH, and AH subplots (10%) than on C subplots (56%). The application of TSP and potash in April 2004 also resulted in less grass cover (11%) than on the unfertilized plots (17%) but significantly more woody plant cover (26%) than on the unfertilized plots (18%).

Pine straw harvesting on the PBH and AH subplots resulted in more grass cover (an average of 20%) than on PB subplots that had 11% grass cover in 2004 (Table 2). Grass cover was greater on AH subplots (27%) than on PBH subplots (14%).

Significant relationships were found between grass and forb yields and height and crown width of understory trees and shrubs or number of woody vine per acre in September 2002 (Table 3). For grasses, the adjusted coefficient of determination (adj-R^2) ranged from 0.15 to 0.36, and for forbs, the adj-R^2 ranged from 0.15 to 0.41 in these relationships. However, number of trees and shrubs per acre was not significantly related to herbaceous plant yields for forbs ($P = 0.578$) or grasses ($P = 0.581$).

In both September 2003 and 2004, the estimation of grass and herbaceous plant cover with woody plant cover as the regressor was significant at $P = 0.0001$ or better for all models (Table 3). Clearly, management activities that stressed and reduced woody vegetation resulted in more herbaceous plant cover.

For all three measurement dates, none of the predictions using multiple independent variables were useful, i.e., they did not significantly increase the predictive power of the model over using a single independent variable. Only the significant equations using a single independent variable were reported in Table 3.

In September 2004, the most widely distributed understory trees and shrubs over 4.5 ft tall were American beautyberry (*Callicarpa americana* L.), blueberry (*Vaccinium* spp.), sassafras (*Sassafras albidum* [Nutt.] Nees), sweetgum (*Liquidambar styraciflua* L.), winged sumac (*Rhus copallinum* L.), and yaupon (*Ilex vomitoria* Aiton). The three fertilizer applications did not significantly affect number and stature of understory trees and shrubs over 4.5 ft tall (Table 4).

Table 3. Significant regression relationships between herbaceous and woody plants at three measurement dates.[a,b]

Dates of measurements	Probabilities	Coefficients of determination	
September 2002[c]			
Grass = 417.13–144.26 (Height)	Probability > |t| = 0.0002	R^2 = 0.3798	Adj-R^2 = 0.3591
Grass = 441.21–266.58 (Width)	Probability > |t| = 0.0004	R^2 = 0.3456	Adj-R^2 = 0.3238
Grass = 316.33–0.0104 (Vines)	Probability > |t| = 0.0169	R^2 = 0.1759	Adj-R^2 = 0.1484
Forbs = 203.48–71.32 (Height)	Probability > |t| = <0.0001	R^2 = 0.4284	Adj-R^2 = 0.4093
Forbs = 213.16–128.41 (Width)	Probability > |t| = 0.0002	R^2 = 0.3702	Adj-R^2 = 0.3492
Forbs = 152.11–0.0049 (Vines)	Probability > |t| = 0.0173	R^2 = 0.1747	Adj-R^2 = 0.1472
September 2003[d]			
Grass = 23.49–0.2825 (Wood)	Probability > |t| = <0.0001	R^2 = 0.4357	Adj-R^2 = 0.4169
Herb = 51.31–0.4828 (Wood)	Probability > |t| = <0.0001	R^2 = 0.4040	Adj-R^2 = 0.3841
September 2004[e]			
Grass = 20.44–0.2948 (Wood)	Probability > |t| = 0.0001	R^2 = 0.4003	Adj-R^2 = 0.3803
Herb = 44.43–0.5448 (Wood)	Probability > |t| = <0.0001	R^2 = 0.6895	Adj-R^2 = 0.6791

[a] The pine straw was harvested nine times from 1992 through 2002 and two more times from 2003 through 2004.
[b] Fertilizer was evenly broadcast over the entire main plot at three times: 45 lb N and 50 lb P/ac in April 1991 and May 1997 and with 50 lb P and 72 lb K/ac in April 2004.
[c] Where grass and forbs are in lb/ac, height (Height) and crown width (Width) are in ft, and vines are in number per acre.
[d] Where grass, herbaceous plant (Herb), and woody plant (Wood) cover values are expressed as percentages.
[e] Where grass, herbaceous plant (Herb), and woody plant (Wood) cover values are expressed as percentages.

Table 4. Number and stature of understory trees and shrubs over 4.5 ft tall in September 2004.

Main plot and subplot treatments		Stems per acre (count)	dbh (in.)	Crown width (ft)
No fertilizer				
C		600	0.14	1.6
PB		0	0	0
PBH		0	0	0
AH[a]		200	0.10	1.2
No fertilizer average		200	0.06	0.7
Thrice fertilized[b]				
C		2,950	0.44	3.5
PB		500	0.10	0.6
PBH		0	0	0
AH[a]		0	0	0
Fertilization average		863	0.14	1.0
Analysis of variance	df[c]		Probability >F-value	
Block	3	0.4773	0.4533	0.6429
F	1	0.5128	0.2420	0.5269
Main EMS[c]	3	28.2092	0.02215	1.54015
ST	3	0.0011	0.0002	0.0002
C versus (PB + PBH + AH)/3	1	0.0001	<0.0001	<0.0001
PB versus (PBH + AH)/2	1	0.9329	0.5982	0.9820
PBH versus AH	1	0.1793	0.3469	0.2266
F × ST interactions	3	0.0428	0.0080	0.0367
Subplot EMS	18	29.5833	0.01145	0.89974

C, control; PB, prescribed burn; PBH, prescribed burn and two harvests; AH, annual harvest; ST, subplot treatments; F, fertilization; df, degrees of freedom; EMS, error mean square.
[a] The pine straw was harvested 11 times from 1992 through 2004.
[b] Fertilizer was evenly broadcast over the entire main plot at three times—45 lb N and 50 lb P/ac in April 1991 and May 1997 and with 50 lb P and 72 lb K/ac in April 2004.
[c] Counts were logarithmically transformed before analysis.

However, the C subplots had greater number and stature of trees and shrubs than the PB, PBH, and AH subplots. Four of the subplot treatments had no trees and shrubs over 4.5 ft tall on the five 1.0-milacre plots: the no fertilizer-PB and -PBH subplots and the fertilized-PBH and -AH subplots. There were significant fertilization-by-subplot interactions affecting number and stature of trees and shrubs. As expected, the fertilized-C subplots had the most trees and shrubs of the greatest stature, followed by the unfertilized-C, fertilized-PB, and unfertilized-AH subplots.

Discussion

Ranges managed for cattle on the Longleaf Tract were rotationally prescribe burned in winter or early spring every 3 years to top kill woody plants, control undesirable herbaceous plants (e.g., cutover muhly [*Muhlenbergia expansa* (Poir.) Trin.]) and remove litter, thereby creating conditions for increased production of desirable herbaceous plants (Duvall 1962, Duvall and Whitaker 1964). However, over the 3-year period between prescribed fires, litter re-accumulated to its preburn levels, and accumulating litter and woody plant regrowth smothered and overtopped grasses (Duvall 1962, Duvall and Whitaker 1964, Haywood 2009a). If the interfire period is extended for several more years, unburned longleaf pine woodlands lose most of their herbaceous plant cover (Haywood 2009a).

Therefore, PB, PBH, and AH subplots did not have major differences in understory plant cover because all three subplot treatments were reducing understory woody plant stature and removing litter. The mechanical activity of the pine straw harvesting equipment further helped to significantly reduce the density of understory trees and shrubs compared with only prescribed burning. Likewise, mechanical activities influenced how much grass and total herbaceous plant cover developed compared with only applying fire.

Herbaceous plant yield and cover decreased as understory trees and shrubs stature, number of woody vines per acre, or woody plant cover increased. Although the number of trees and shrubs per acre was a poor predictor of grass and forb yields, these results nevertheless support the observation that brushy, unburned understories lead to a decline in grass and forb production because of crowding, shading, and litter accumulation, as well as root competition for water and nutrients (Haywood et al. 2001).

Percentage of grass cover increased after fertilization, but a general lack of response by the herbaceous vegetation to three nutrient amendments was probably because competition from the overstory trees, prescribed burning, and harvesting operations kept herbaceous and woody plant communities in a continual state of change on both unfertilized and fertilized plots. Additionally, woody plant cover did not respond to fertilization until potash was applied, which suggested that a K deficiency was limiting woody plant development.

Both applications of DAP were low in N on the basis of pine straw management recommendations by Morris et al. (1992) and Blevins et al. (1996/2005), and the overstory longleaf pine trees did not respond to the applied rates of fertilizer in this study as well (Haywood 2009b). A low rate of N was applied because fertilizer rates were selected on the basis of P recommendations for the Southeast and not on N recommendations (Allen 1987). Since 1987, fertilization recommendations to increase foliage yields have become more widely available (Morris et al. 1992, Blevins et al. 1996/2005). Had the recommendations of Morris et al. (1992) and Blevins et al. (1996/2005) been followed, a higher application rate of N might have resulted in a greater growth response by understory vegetation in this study.

Nevertheless, either prescribed fire or pine straw harvesting can be used to create and maintain open forest conditions for wildlife habitat, esthetics, better access, or other reasons. The ability of prescribed fire and pine straw harvesting to change understory composition is reminiscent of how cattle changed plant cover by trampling vegetation, destroying more herbage than they ate (Pearson 1975) but helping to keep the range relatively free of brush (Duvall 1962).

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