Influence of Pine Straw Harvesting, Prescribed Fire, and Fertilization on a Louisiana Longleaf Pine Site

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ABSTRACT

This research was initiated in a 34-year-old, direct-seeded stand of longleaf pine (*Pinus palustris* Mill.) to study how pine straw management practices (harvesting, fire, and fertilization) affected the longleaf pine overstory and pine straw yields. A randomized complete block split-plot design was installed with two main plot treatments: (1) no fertilization and (2) fertilization with 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. There were four subplot treatments: (1) control—no activity except a standwide thinning in June 1999, (2) prescribed burn 6 times from March 1991 through May 2004, (3) prescribed burned as in subplot treatment 2 and pine straw harvested in early 1992 and 1993, and (4) annual harvest of pine straw 13 times from early 1992 through April 2006. Fertilization did not affect longleaf pine growth and yield over the 15-year study. Subplot management also did not influence longleaf pine growth possibly because the adverse effects that competition, repeated prescribed burning, and litter removal have on longleaf pine growth could not be separated among subplot treatments. Fertilization did not directly affect pine straw yields; however, it appeared that pine straw yields decreased over time.

Keywords: direct seeding, diammonium phosphate, *Pinus palustris* Mill., potash, triple superphosphate

Longleaf pine (*Pinus palustris* Mill.) forests once constituted a major ecosystem in the southern United States stretching from southeastern Virginia south to central Florida and west into east Texas (Outcalt and Sheffield 1996). These forests covered a wide range of site conditions, from wet pine flatwoods to dry mountain slopes. Intensive exploitation reduced the extent of old-growth longleaf pine forests to 3.2 million ac by 1993 (Outcalt and Sheffield 1996).

Much of the remaining longleaf pine forests are in a fragmented landscape of mostly public lands and a few scattered private or institutional holdings (Johnson and Gjerstad 1996). To restore longleaf pine to a significant and viable forest component across the southeastern United States, private landowners need to perceive the economic potential of managing longleaf pine stands for producing timber with high percentages of pole- and piling-grade trees, forage, and pine straw as well as the incorporation of hunting leases.

Pine straw has traditionally been harvested for mulch (Bateman and Wilson 1961, Mississippi State University [MSU] 2008). Adding pine straw to timber and forage as products of management can increase profits substantially, and the income from straw may exceed that from timber (Roise et al. 1991). Yields from longleaf pine stands of at least 80 ft^2/ac of basal area should exceed 2,200 lb/ac of pine straw annually and at 120 ft^2/ac of basal area, the best stands should produce over 4,000 lb/ac of pine straw annually on a dry weight basis (Blevins et al. 1996). Despite its economic opportunities, repeated removal of the forest floor may adversely affect pine tree growth (Jemison 1943, Ginter et al. 1979). Therefore, fertilization is often recommended where pine straw is being harvested (Morris et al. 1992, Blevins et al. 1996).

This research was initiated in 1990 to study pine straw management practices in a 34-year-old, direct-seeded stand of longleaf pine previously managed for cattle grazing, and treatments began in 1991. The study objectives were to determine how management practices influenced longleaf pine productivity, pine straw yields, seasonal needle fall, foliar nutrition, fire effects, soil properties, plant nutrition, understory vegetation, and species richness. The 1991 through early 1997 results were summarized by Haywood et al. (1998). This article addresses the influences of management on the longleaf pine overstory and pine straw yields from December 1997 through December 2006.

Methods

Site Description

The 250-ac study area is on the Kisatchie National Forest in central Louisiana (approximately 92°36′00″W, 31°00′30″N at 160 ft above sea level). The area's climate is subtropical, with mean January and July temperatures of 47° and 82°F, respectively (Louisiana Office of State Climatology 1999). Annual precipitation averages 60 in. with more than 38 in. during the 250-day growing season, which is from March 10 to November 15.

The study site is gently rolling Ruston (fine-loamy, siliceous, semiactive, and thermic Typic Paleudults) and Smithdale (fine-loamy, siliceous, subactive, and thermic Typic Hapludults) fine sandy loam soils (Kerr et al. 1980) with a site index of 86 ft (base age 50 years) for longleaf pine. Slopes vary from 1 to 8%. 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 (PB) on a 3-year interval as part of a range management program, which suppressed development of understory woody vegetation. The whole site was last burned in 1987 before study initiation.

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Thinning of the site to a target basal area of 65 ft^2/ac was conducted in June 1999 to maintain stands within the 50- to 80-ft^2/ac basal area range recommended for red-cockaded woodpecker (*Picoides borealis*) habitat (US Fish and Wildlife Service [USFWS] 2009). Additionally, it was thought that by reducing stand stocking the remaining trees would have sufficient growing space to better respond to management. Before thinning, basal area on the subplots ranged from 103 to 111 ft^2/ac and averaged 107 ft^2/ac. The subplots were thinned from below to a residual basal area of 62–66 ft^2/ac and averaged 64 ft^2/ac. The criteria for selecting trees to be cut were (1) removal of scattered loblolly pine trees (*Pinus taeda* L.), (2) removal of longleaf pine trees in the intermediate crown class and ones with poor form or having diseased or injured boles, and (3) provide better spacing between residual trees.

Treatment Establishment

Four, 3.2-ac research blocks were installed in the spring and early summer of 1990 in a randomized complete block split-plot design with the four blocks as replicates. Blocking was based on initial overstory basal area and topography. In total, there were 32, 0.39-ac subplots (4 blocks by 2 main plots by 4 subplots per main plot). An interior 0.23-ac area within each 0.39-ac subplot was used for measurement and sampling purposes. In August 1990, the understory vegetation was rotary mowed to create uniform understory conditions and to facilitate plot establishment.

The two main-plot treatments within each block were (1) no fertilization and (2) fertilization—plots were fertilized three times with 45 lb N and 50 lb P/ac broadcast evenly over the main plot as 250 lb/ac of diammonium phosphate in April 1991 and May 1997 and with 50 lb P and 72 lb K/ac as 250 lb/ac triple superphosphate and 250 lb/ac of potash, respectively, in April 2004. The four subplot treatments were control (C)—no prescribed fire after 1987 or rotary mowing after 1990; prescribed burned (PB)—subplots were burned in March 1991, February 1994, March 1997, January 2000, June 2002, and May 2004; prescribed burned and two straw harvests (PBH)—subplots were prescribed burned along with the PB subplots, and the pine straw was harvested in early 1992 and 1993; and annual straw harvest (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 (Table 1). All subplots were thinned as part of a standwide thinning in June 1999.

Hurricane Lili passed through central Louisiana on Oct. 4, 2002. It spawned a small tornado or shearing wind that disproportionally felled longleaf pine trees across the study site. On the PBH subplots, six trees were lost (average dbh of 13 in.), whereas only three trees were lost on the other three subplot treatments (average dbh of 13 in.). No other natural phenomenon caused significant damage to the study.

Pine Straw Harvesting and Dry Weight Determination

The potential detriment to forest vegetation from one to two pine straw harvests over a 10-year period is a management concern of the US Forest Service. To address this concern, harvesting stopped on PBH subplots once it was apparent that there were no statistical differences in pine straw yields between PBH and AH subplots (Haywood et al. 1998). Prescribed burning continued as part of the PBH subplot treatment just as it would have normally continued on US Forest Service lands.

Table 1. Chronological listing of management activities on the subplot treatments from August 1990 through April 2006.

Dates	Activity and subplot treatment
August 1990	Rotary mowed C, PB, PBH, and AH
March 1991	Prescribed burned PB and PBH
July 1991	Rotary mowed PBH and AH
August 1991	Prescribed burned AH
March/April 1992	Harvested pine straw on PBH and AH
July 1992	Rotary mowed PBH and AH
March/April 1993	Harvested pine straw on PBH and AH
July 1993	Rotary mowed AH
February 1994	Prescribed burned PB and PBH
April 1994	Harvested pine straw on AH
July 1994	Rotary mowed AH
January 1995	Harvested pine straw on AH
July 1995	Rotary mowed AH
February 1996	Raked pine straw off AH
July 1996	Rotary mowed AH
March 1997	Prescribed burned PB and PBH
April 1997	Raked pine straw off AH
July 1997	Rotary mowed AH
April 1998	Raked pine straw off AH
June 1999	Thinned C, PB, PBH, and AH
January 2000	Prescribed burned PB, PBH, and AH
October 2000	Rotary mowed AH
January 2001	Raked pine straw off AH
July 2001	Rotary mowed AH
January 2002	Harvested pine straw on AH
June 2002	Prescribed burned PB and PBH
July 2002	Rotary mowed AH
February 2003	Harvested pine straw on AH
July 2003	Rotary mowed AH
January 2004	Harvested pine straw on AH
May 2004	Prescribed burned PB and PBH
July 2004	Rotary mowed AH
April 2005	Raked pine straw off AH
July 2005	Rotary mowed AH
April 2006	Harvested pine straw on AH

The subplot abbreviations are C, control; PB, prescribed burned; PBH, prescribed burned and two straw harvests; and AH, annual straw harvest.

The PBH and AH subplot treatments were rotary mowed in July 1991 (Table 1). 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, and the straw was mechanically baled in early 1992 and removed from the site and used for erosion control. The PBH and AH subplots were again rotary mowed in July 1992 and the straw was harvested in early 1993. Straw harvesting continued on the AH subplots with rotary mowing in July 1993 and 1994 and straw harvesting in April 1994 and January 1995. The bales were weighed and a subsample was taken to determine moisture content and dry matter production in pounds per acre for the 1992 through 1995 harvests (Haywood et al. 1998). In this early period, removal of all pine straw was attempted and some understory vegetation was uprooted. As a result, more forest floor material was removed than was added on a yearly basis as needle fall, and the mineral soil was eventually left bare on much of the harvested surface 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.

For the 1996, 1997, and 1998 harvests, AH subplots were raked to collect the straw before it was moved off the subplots and left in the surrounding woods because personnel were not available for baling and weighing bales (Table 1). All subplots were thinned in June 1999. Pine straw was not harvested in 1999 to allow a fuel bed to develop before the prescribed burn on the PB, PBH, and AH subplots 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 (Table 1). However, pine straw was again baled, weighed, and removed from the site after 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. From 2001 through 2006, only current-year pine straw was removed and some material was left near trees and stumps, in depressions, and among understory vegetation.

After the pine straw bales were weighed following the 2002, 2003, 2004, and 2006 harvests, a subsample of straw was taken from the center of each bale, and the subsamples were weighed and dried at 175°F for 72 hours in a forced-air oven to determine oven-dried weight. The wet and dry weights of the subsamples were used to determine percent dry matter in the samples, and the percent dry matter was used to calculate the dry weight (in pounds per acre) of the harvested pine straw.

Prescribed Fire

Prescribed burning was done with strip head fires, which were monitored to determine their intensity in 1991 and 1994 (Haywood et al. 1998). One month after the 1991 and 1994 prescribed burns, the percentage of crown scorch was estimated for each pine tree on the PB and PBH subplots. Crown scorch averaged 15 and 11% after the March 1991 and February 1994 burns, respectively. Fire intensity was not determined for the remaining four prescribed burns. The AH subplots were no longer protected from fire beginning in January 2000, but the fires only fingered into them and went out because the sparse fuel bed was not continuous enough to carry a fire.

Longleaf Pine Sampling

Total height and dbh of all overstory pine trees in the 0.23-ac measurement area of each plot were measured using a laser hypsometer (Criterion 400 Survey Laser; Laser Technology, Inc., Centennial, CO) and diameter tape, respectively. The trees were measured in December 1997 (18 months prethinning), September 1999 (3 months postthinning), and December 2006 (90 months postthinning). The outside-bark (o.b.) stem volume and green weight of stemwood per tree were calculated using the relationships of Baldwin and Saucier (1983).

Data Analysis

For the weights of pine straw harvested in 2002, 2003, 2004, and 2006, a randomized complete block design model was used to compare the two fertilization levels. For longleaf pine, dependent variables were outside-bark (o.b.) stem volume per tree and number of trees, basal area, volume, and green weight of stemwood per acre. The prethinning measurements made in December 1997 and the postthinning measurements made in September 1999 were subjected to analyses of variance for a randomized complete block split-plot design model to determine if thinning changed treatment effects. Additionally, an analysis of covariance with the December 2006 results as the dependent variable and the September 1999 (postthinning) measurements as the covariate was conducted. For all analyses of variance, orthogonal linear contrasts were used to compare subplot treatments: (1) control versus management (PB + PBH + AH), (2) prescribed fire (PB) versus pine straw harvesting (PBH + AH), and (3) two harvests (PBH) versus annual harvest (AH). All main, subplot, and interaction effects were considered significant at $P \leq 0.05$.

Table 2. Oven-dried weight of pine straw harvested annually from 2002 through 2006 (9th through 13th harvests).

Main plot treatments	January 2002	February 2003	January 2004	April 2005	April 2006
	lb/ac				
No fertilizer	1,563	1,339	1,712	—	1,611
Fertilized[a]	1,554	1,466	1,991	—	1,942
	Probability > F-value				
Block[b]	0.567	0.578	0.010	—	0.406
Fertilizer	0.953	0.413	0.005	—	0.268

—, No data were collected although pine straw was removed.
[a] 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 50 lb P and 72 lb K/ac in April 2004 (after the January 2004 harvest).
[b] Blocking was based on initial overstory basal area and topography.

Results and Discussion

Pine Straw

In earlier years (1992–1995), there were no differences in the weights of harvested pine straw (Haywood et al. 1998). Despite the thinning in June 1999, fertilized plots continued to produce no more pine straw than the unfertilized plots in 2002 and 2003 (Table 2). However, the harvest in January 2004 on the fertilized plots was significantly greater than the harvest on the unfertilized plots by a difference of 279 lb/ac. Although plots were again fertilized in April 2004, the 331-lb/ac difference in pine straw harvested in April 2006 was not significant between the two fertilization levels. Therefore, over 13 annual harvests in 15 years, fertilization did not have a consistent yearly effect on pine straw yields in this direct-seeded longleaf pine stand. In contrast, Chastain et al. (2007) reported that applying granular fertilizer (86 lb N, 38 lb P, and 71 lb K/ac) increased production of pine straw in a 22-year-old longleaf pine stand by 26% over a 3-year period.

Longleaf Pine

Earlier in this study, management practices affected longleaf pine growth from 1991 through 1994, but these responses were no longer statistically significant after the 1995 growing season (Haywood et al. 1998). This trend continued, and after the 1997 growing season, the fertilization treatment still did not significantly affect stand stocking, o.b. volume per acre, or volume per tree (Table 3). Basal area per acre in 1997 was significantly greater on the unfertilized plots than on the fertilized plots, but the difference was not biologically important. Additionally, none of the four subplot treatments significantly affected any of the longleaf pine variables in 1997. Across the study and 18 months before thinning, longleaf pine averaged 128 trees/ac, 107 ft^2/ac of basal area, and 3,875 ft^3 or 120 green tn/ac of stemwood, and stem volume averaged 31 ft^3/tree.

The number of pine trees harvested in June 1999 averaged 60 trees/ac. Basal area was reduced by 43 ft^2/ac, and 1,431 ft^3 or 44 green tn/ac of stemwood was harvested. Three months after thinning, there were no statistical differences in the residual pine variables between the two fertilization treatments or among the four subplot treatments. Across the study in September 1999 longleaf

Table 3. Longleaf pine stocking, basal area, and o.b. volume per acre and volume per tree in December 1997, September 1999 after a June 1999 selective thinning of the overstory pine trees, and in December 2006, 90 months postthinning.

		December 1997				September 1999				December 2006			
Main plot and subplot treatments		Trees per acre no.	Basal area per acre	o.b. Vol per acre	o.b. Vol per tree	Trees per acre no.	Basal area per acre	o.b. Vol per acre	o.b. Vol per tree	Trees per acre no.	Basal area per acre	o.b. Vol per acre	o.b. Vol per tree
Main plots			ft^2	.... ft^3			ft^2	.... ft^3			ft^2	.... ft^3	
No fertilizer		129	108	3,930	31	67	65	2,462	37	65	78	3,003	46
Thrice fertilized[a]		128	106	3,820	30	69	64	2,426	35	67	78	3,032	45
Subplot treatments													
Control (C)		126	106	3,869	31	68	65	2,505	37	66	80	3,132	47
Prescribe burned (PB)		131	108	3,948	30	68	64	2,447	36	67	79	3,061	46
PB and two harvests (PBH)		129	108	3,933	31	70	65	2,489	36	64	75	2,940	46
Annual harvest (AH)[b]		126	107	3,748	30	66	63	2,335	35	65	78	2,938	45
Analyses of variance	df[3]						Probability > *F*-value						
Block[c]	3	0.007	<0.001	0.011	0.014	0.077	0.086	0.376	0.027	0.748	0.740	0.849	0.913
Fertilizer (F)	1	0.828	0.023	0.248	0.261	0.544	0.443	0.657	0.265	0.820	0.582	0.493	0.320
Main EMS	3	95.11	2.43	46,744	2.916	0.007	8.75	41,804	9.44	0.004	42.26	75,919	3.208
Subplot treatments (ST)	3	0.881	0.624	0.247	0.994	0.824	0.867	0.313	0.966	0.061	0.103	0.099	0.283
C vs PB + PBH + AH	1	0.657	0.341	0.930	0.795	0.925	0.569	0.315	0.722	0.643	0.538	0.539	0.612
PB vs PBH + AH	1	0.616	0.571	0.254	0.933	0.906	0.861	0.674	0.894	0.087	0.164	0.312	0.199
PBH vs AH	1	0.663	0.487	0.095	0.958	0.361	0.559	0.126	0.738	0.034	0.045	0.032	0.168
F × ST interactions	3	0.381	0.157	0.650	0.690	0.234	0.734	0.896	0.324	0.437	0.553	0.642	0.433
Covariate	1									<0.001	<0.001	<0.001	<0.001
Subplot EMS	17/18	217.2	17.25	44,029	19.80	0.022	19.67	36,356	28.85	0.004	19.15	26,983	1.751

df, Degrees of freedom; EMS, error mean square; subplot EMS had 18 df for analyses without a covariate and 17 df for analyses with a covariate.
[a] 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 50 lb P and 72 lb K/ac in April 2004.
[b] The pine straw was harvested 13 times from 1992 through 2006.
[c] Blocking was based on initial overstory basal area and topography.

pine averaged 68 trees/ac, 64 ft^2/ac of basal area, and 2,444 ft^3 or 76 green tn/ac of stemwood, and stem volume averaged 36 ft^3/tree (Table 3).

Ninety months after thinning, fertilization still had not significantly influenced longleaf pine basal area and volume per acre or volume per tree (Table 3). Longleaf pine stocking, basal area, and volume per acre were significantly less on PBH subplots than on AH subplots when the September 1999 measurements were used as a covariate. However, this was likely caused by a disproportionate loss of trees on PBH subplots during Hurricane Lili than by a direct treatment effect, because the volume per tree was not significantly different between PBH and AH subplots. In other research, application of 200 lb N, 42 lb P, and 84 lb K/ac at a stand age of 1 year increased longleaf pine growth through 25 growing seasons when competing vegetation was also controlled (Schmidtling 1987). However, Haywood (2007) found no beneficial effect on 6-year-old longleaf pine trees from applying 32 lb N and 36 lb P/ac at planting to soils similar to the ones in this study. Similarly, Chastain et al. (2007) reported that fertilization did not significantly influence the growth of 22-year-old longleaf pine trees in stands with 129 ft^2/ac of basal area.

Management Implications

The removal of pine straw on a continual basis was shown to deter fire spread during latter prescribed burns because fires fingered into harvested areas and went out because of the sparse fuel bed. Harvesting activities kept the stocking of understory arborescent plants and the size of larger trees and shrubs in check, also deterring fire spread by removing fuel ladders. Therefore, harvesting pine straw may be used to create fire breaks across landscapes to disrupt wildfires. Such buffers could be installed near buildings and other structures as a fire control measure at no cost to the property owner.

Fertilization rate may explain why there was no significant increase in straw yields except in 2004. The original rates, 45 lb N and 50 lb P/ac broadcast twice in a 6-year interval, may not have applied enough N because the fertilizer rate was selected based on P recommendations for the Southeast and not on N recommendations (Allen 1987). Since 1991, fertilization recommendations to increase foliage yields have become more widely available. For general pine straw management, Morris et al. (1992) recommends 200 lb N, 50 lb P, and 50 lb K with repeated applications on a 5-year interval under conditions of annual pine straw harvesting on soils and stand conditions similar to the ones in this study. However, longleaf pine has lower N and P nutritional needs than loblolly and slash pine (*Pinus elliottii* Engelm.; Allen 1987, Blevins et al. 1996). For longleaf pine, Blevins et al. (1996) recommends a maximum single application of 100 lb N, 25 lb P, and 50 lb K/ac, with repeated applications on a 6- to 7-year interval under conditions of annual pine straw harvesting.

The N-fertilization rate might have been too low to be effective, although this effect was not expressed as a downward trend in pine straw harvested from 2002 through 2006 (Table 2). However, yields from 1992 through 1995 averaged 5,108 lb/ac (Haywood et al. 1998) and yields from 2002 through 2006 averaged 1,647 lb/ac. Direct comparisons between the two periods were not possible because in the earlier period removal of all forest floor material was done, while in the later period, only current-year pine straw was harvested and some material was left near trees and stumps, in depressions, and among understory vegetation. Additionally, from 1992 through 1995 basal area ranged from 86 to 102 ft^2/ac (Haywood et al. 1998) and from 2002 through 2006, basal area ranged from 69 to 78 ft^2/ac after the 1999 thinning. This change in basal area should result in lower pine straw yields (Blevins et al. 1996). The differences in harvesting techniques and changes in stand conditions might explain much of the 68% decrease in yields between the two periods. However, an average yield of 1,647 lb/ac from 2002 through 2006 was only 58% of the annual pine straw production predicted by Blevins et al. (1996) for a site with a basal area of 74 ft^2/ac and a site index of 86 ft (base age, 50 years) as in this study. Given these facts, a decrease in pine straw yields after 13 harvests over a 15-year period is suspected. Therefore, to maintain high yields, land managers should follow Blevins et al. (1996) fertilizer rates and interval between applications where longleaf pine straw is annually harvested.

If needle fall is decreasing with annual harvesting, longleaf pine growth should have been adversely affected although there were no management differences in growth. Possibly, growth is being negatively affected on the other three subplot treatments as well. Understory competition for water and nutrients, fire-related changes in soil physical properties, and heat injury to pine trees have reduced longleaf pine growth in other studies (Boyer and Miller 1994, Haywood 2002, 2007). The increasing woody plant competition on the control and the repeated prescribed burning on PB and PBH subplots may have caused declines in growth that can not be separated among subplot treatments given the methodology used to measure trees and the inherent variability associated with working across a 250-ac site. Nevertheless, in this 15-year study pine straw harvesting and repeated prescribed burning did not adversely affect longleaf pine growth and yield.

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