Longleaf Pine Site Response to Repeated Fertilization and Forest Floor Removal by Raking and Prescribed Burning

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Cover Photo

Longleaf pine (*Pinus palustris* P. Mill.). (photo courtesy of W. Robert Maple, USDA Forest Service, Bugwood.org)

ABSTRACT

Removal of forest floor litter by pine needle raking and prescribed burning is a common practice in longleaf pine (*Pinus palustris* Mill.) stands on Coastal Plain sites in the Southeastern United States. Repeated removal of litter by raking and the loss of surface organic matter from controlled burns can affect the already low fertility of these sites. Although fertilization may compensate for some nutrient losses, long-term changes in soil chemical properties may still negatively affect productivity. In this experiment, we continue work that examined the effect of burning, fertilization, and moderate and intensive litter raking on tree growth, litter production, and soil chemistry in longleaf pine stands over 6 years. This report discusses treatment response 9 years after selective thinning was initiated in a longleaf pine plantation in Aiken County, SC. Litter raking treatments, when compared to the control treatment, did not significantly affect tree height or basal area growth, although averages were larger in the fertilized litter raking treatments when compared to the non-fertilized litter raking treatments. However, longleaf pine litter production declined by up to 30 percent in both burned and raked treatments without fertilizer application compared to the unfertilized control. Fertilization significantly increased litter production on control plots, and it appeared to mitigate the reductions in needle fall on burned and raked plots. Soil nitrogen concentrations increased on fertilized and unfertilized burned and raked treatments when compared to the corresponding control. Results indicate moderate fertilization can sustain long-term litter removal and maintain soil nutrients in longleaf pine stands.

Keywords: Burning, fertilization, longleaf pine, raking, site response.

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Dr. Kim H. Ludovici acquired this study while it was in progress and was instrumental in bringing it to conclusion. Although she died before she was able to complete this report, her analysis and interpretations are a major part of this paper. Without her dedication and enthusiasm, this paper would not have been published.

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INTRODUCTION

Longleaf pine trees annually drop a full foliage cohort onto the forest floor. This needle litter, called pine straw, can be raked and sold for use as landscaping mulch, which provides landowner income. For example, forest landowners in Georgia received an estimated \$15.5, \$17.5, and \$22.4 million from pine straw sales in 2000, 2001, and 2002, respectively (Boatright and McKissick 2003); \$81 million in revenues from longleaf, loblolly, and slash pine straw in 2009 (Dickens and others 2012); and \$56.3 million from pine straw sales in 2013 (Wolfe and Stubbs 2014). North Carolina landowners received an estimated \$34.8 million from pine straw sales in 2015 (McConnell and others 2016). Pine straw raking also reduces wildland fire fuels because raking management practices generally minimize shrub cover and eliminate available fine fuels. Despite these benefits, there are also concerns about pine straw removal, most importantly the depletion of nutrients on already nutrient poor sites and the effects on surface soil moisture availability (Ginter and others 1979). After several research studies, there is little agreement on the impacts of pine straw raking on long-term site attributes, although fertilization has been shown to improve straw production (Blevins and others 2005, Chastain and others 2007, Dickens 1999, Lopez-Zamora and others 2001, Ogden and Morris 2004, Pote and others 2004, Ross and others 1995).

Longleaf pine litter yield can be as much as 3,000–5,000 pounds per acre (3362–5604 kg/ha) (Blevins and others 2005, Ogden and Morris 2004, Ross and others 1995). This litter can contain up to 52 percent carbon (C) and 0.60 percent nitrogen (N) (180–300 pounds per acre [202–336 kg/ha N]), 0.06 percent phosphorous (P) (18–30 pounds per acre [20.2–33.6 kg/ha P]), and substantial quantities of the cations [calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe)] (Blevins and others 2005). Nitrogen has been shown to be deficient on many forest sites in the Southeastern United States and P deficiencies are widespread (Allen 1987). Pine straw raking can further remove this pool of nutrients, particularly if repeated (Ginter and others 1979, Morris and others 1992), and may result in decreased growth of the overstory trees as well as reduced leaf area and litter production on these traditionally nutrient poor sites. It has been suggested that fertilization could compensate for the loss of nutrients due to litter raking (Blevins and others 2005, Chastain and others 2007, Dickens 1999, Haywood and others 1995, Morris and others 1992, Ogden and Morris 2004), but long-term results of this potential mitigation strategy have not been reported.

Studies of prescribed fire application in longleaf pine stands in the Southeastern United States suggest repeated prescribed fires may decrease stand growth and increase tree mortality (Boyer 1987, Otrosina and others 1999); however, there are limited data on fire impacts on soil nutrients (McKee 1982, Schoch and Binkley 1986, Waldrop and others 1987, Wan and others 2001). Depending on conditions, low-intensity prescribed fires can burn between 30 to over 80 percent of the forest floor, by weight (Caldwell and others 2002, McKee 1982), leaving a substantial protective cover of decayed humus over the mineral soil as well as mineral ash (Hough 1978, Ralston and others 1983). Low-intensity fires may provide a pulse of available N, which may increase the rate of forest floor decomposition (Schoch and Binkley 1986). Heyward and Barnette (1934) and later McKee (1982) and Waldrop and others (1987) noted slight accumulations of N in the surface of sandy loam soils following prescribed fires. However, high-intensity prescribed fires that consume a high percentage of the forest floor may damage or kill fine roots, leaving trees more susceptible to beetle attacks and root diseases (Otrosina and others 1999, Sullivan and others 2003).

Ross and others (1995) reported no significant raking or burning treatment effects on longleaf basal area, mortality, soil chemical properties, or litter physical and chemical properties in a study from 1987 until 1993. With continued research, we report results of a long-term study to evaluate the effects of repeated pine straw raking, prescribed burning, and fertilization on a longleaf pine plantation. Specifically, our research objectives were to: 1) evaluate the growth of longleaf pine under repeated litter removal by raking or burning; 2) quantify N and P in the forest floor and surface soil; 3) determine if supplemental N and P applications alter tree growth, pine straw production, and/or forest floor properties; and 4) identify management treatments that would enable sustainable pine litter production. Since the study began in 1987, the longleaf stands underwent five 3-year cycles of treatments (i.e., raking, burning, and fertilization). The stands were selectively thinned in 1993, and the treatments continued through 2002. This report provides results from 1994 to 2002.

METHODS

The study site is located on the U.S. Department of Energy's Savannah River Site (SRS), a national environmental research park near Aiken, SC, in the Carolina sandhills physiographic region in Aiken County, SC, USA, which is on the Atlantic Coastal Plain [81° 39' 54.97" W, 33° 20' 53.06" N (WGS84)]. The soil is a Fuquay fine sandy loam (Arenic Plinthic Paleudults, loamy, siliceous, thermic) and is well drained with < 2-percent slope. The site is an old agricultural field and has a long history of row crop agriculture. It was converted to forest in 1951 when the SRS was established (Kilgo and Blake 2005). The original longleaf stands were planted at 6 x 10-foot (1.8 x 3.1-m) spacing and thinned in the mid-1970s with approximately half the stems removed. These stands were 34 years old when the mixed hardwood understory was removed by stem cutting and herbicide application in 1986 (Ross and others 1995).

Study Design

In 1987, four litter removal treatments and two fertilization treatments were installed in a split-plot design replicated in two complete blocks (fig. 1) (Ross and others 1995). Each main treatment plot was 0.46 acres. Main plot treatments were: 1) an untreated control with the forest floor allowed to accumulate (Control [C]), 2) prescribed winter burning (Burn [B]), 3) raking and removal of the fresh pine litter (i.e., straw) only (Rake I [RI]), and 4) raking and removal of all forest floor (fresh litter layer + humus layer) (Rake II [RII]). The split-plot fertilization treatments were: 1) no fertilizer (No Fert) or 2) 120 pounds per acre (135.4 kg/ha) of elemental N as urea and 32 pounds per acre (35.9 kg/ha) of elemental P as triple super phosphate (Fert).

Each treatment was repeated every 3 years during the winter months from 1987 through 2002. Raking treatments involved manually removing litter from plots. Fresh pine litter was defined as needles that retained their reddish tint, the straw typically preferred for landscape mulch. Prescribed burns were winter backing fires, where flames did not exceed 18 inches above the ground. About 75 to 80 percent of the forest floor was consumed with these burns, typical of backing fires in these type of stands (Sullivan and others 2003). Fertilizer was applied several months after each raking and burning treatment.

Tree, litter, and soil measurements were generally completed in December or January prior to the next treatment cycle of raking, burning, and fertilization. Immediately following the measurement and treatment applications in 1993, all stands were thinned from below to a basal area of approximately 90 square feet per acre (20.7 m²/ha) to increase uniformity among treatments, allow for growth, and minimize self-thinning mortality since many of the plots had basal areas >150 square feet per acre (34.4 m²/ha). Thinned stems were removed from the plots, and height and diameter measurements of the residual trees were completed immediately following thinning.

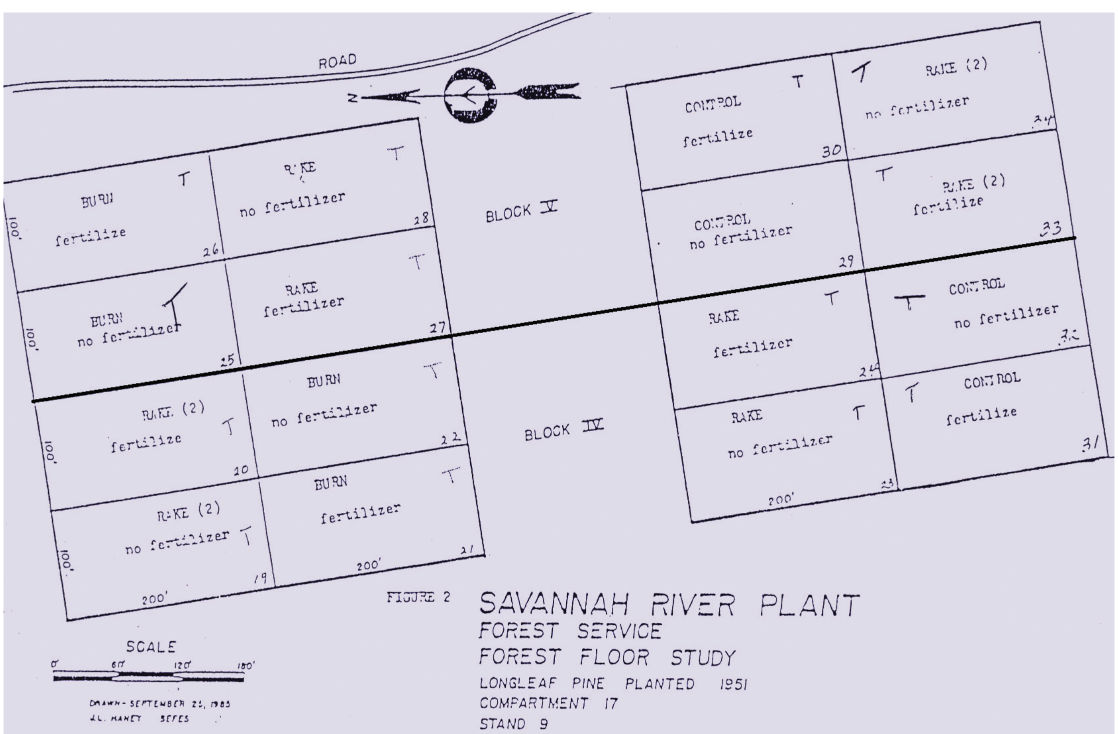

Figure 1—Plot map of litter raking, burning, and fertilization study that began in 1987.

Aboveground Tree and Litter Fall Measurements

The longleaf pine stands were 35 years old when initial measurements for this study were recorded in 1987 (Ross and others 1995). Initial measurements were used to account for stocking variability among plots. Tree height (HT) and diameter at breast height (DBH) were measured on all live trees within each plot at the end of each 3-year treatment rotation. Basal area (BA) was calculated from DBH and the number of stems per area and expressed on a per-area basis. Plot periodic mean annual growth was estimated for every 3-year period as the plot average difference between initial and final measurement divided by 3. Litter fall was collected from April 1997 through October 2001, in five circular raised traps (3.28 feet [1 m] in diameter) randomly placed within each plot. Branches, bark, and pine cones were removed and litter was composited by plot quarterly. This material represented potentially available litter for raking removal as would be done in a commercial harvest. Litter was oven-dried at 149° F (65° C) and dry mass reported on a per-area basis. Litter was analyzed for N and C content using a FlashEA 1112 NC soil analyzer (Thermo Fisher Scientific, Inc.). Litter was analyzed for percent Ca and Mg by dry-ashing followed by weak acid digestion, and percent P was determined using 0.1 N nitric acid digestion (Campbell and Plank 1997).

Forest Floor and Soil Measurements

In 2002, 10 forest floor samples (20.36 square inches [131 cm^2]) were collected in each plot and composited, excluding sticks, cones, and bark. Forest floor material was separated into the fresh litter layer and humus (F + H) and oven-dried at 149° F (65° C) before being ground to pass through a 0.04-inch (1-mm) mesh screen.

Two soil cores, 6 inches (15.2 cm) long and 7/8 inch (2.2 cm) in diameter, were extracted using a push tube at each of the 10 forest floor sample points. Soil samples were air-dried and sieved to pass through a 0.04-inch (1-mm) mesh screen. Soils were analyzed for N and C using a FlashEA 1112 NC soil analyzer (Thermo Fisher Scientific, Inc.). Soils were analyzed for percent organic matter (OM) concentration as well as percent P, Ca, and Mg by dry-ashing followed by weak acid digestion using the Mehlich III method. Soil pH was determined on a 1:1 soil-to-water paste.

Statistical Analysis

HT, BA, DBH, periodic annual growth increment, litter mass and nutrient concentration, and forest floor and soil nutrient concentration were analyzed for main plot and split-plot treatment effects and interactive effects by analysis of variance (ANOVA) using SAS PROC MIXED (SAS 2002). Changes over time in HT, DBH, BA, litter mass, and nutrients were analyzed using repeated measures with unequal time intervals, using spatial power covariance structure. HT and DBH at the beginning of the original study (Ross and others 1995) were subtracted from subsequent measurements to account for initial variation. Treatment effects were considered significant at the $p < 0.05$ level. Where appropriate, comparison of treatment means was performed using the least significant means (LSM) multiple comparison procedure adjusted by Tukey's method.

RESULTS

Tree Growth and Litter Production

We found no significant effects of the repeated burning or litter raking treatments on HT, DBH, or BA over the time period 1993 to 2002 or periodic growth from 1994 to 2002 (table 1). There were no significant differences due to fertilizer treatment for any variables measured from 1994 to 2002, nor was there any significant interaction between main treatment and fertilization or year (i.e., annual growth rate variability). However, HT, DBH, and BA were consistently, but not significantly, higher in the raked and fertilized plots compared to their non-fertilized plots while the opposite was true in the control and burned treatments, and this response continued throughout the study period (figs. 2–4). Initial relative tree size differences tended to carry through the entire study period.

Table 1—Results (p-values) from treatment impact analysis on a longleaf pine stand, 2002

Measurement	Main plot effect Raking & burning response	Split-plot effect Fert response	Interactions Trt * Fert effect
		p-values	
Height (HT)	0.9280	0.1868	0.3171
Diameter (DBH)	0.9870	0.7521	0.4394
Basal area (BA)	0.3518	0.2311	0.2193
Mean incremental HT	0.9815	0.9467	0.6381
Mean incremental DBH	0.5363	0.3570	0.4973
Mean incremental BA	0.6845	0.8770	0.7586
Annual litter fall	0.0505	0.0017	0.1337

Trt = Treatment
Fert = Fertilization

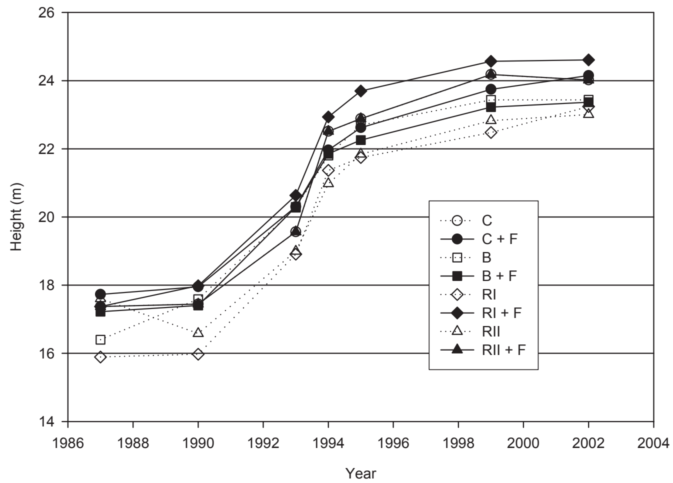

Figure 2—Mean annual height (m) growth increments of mid-rotation longleaf pine. C = Control, F = Fertilization treatment, B = Prescribed winter burn, RI = Raking and removal of fresh pine litter, RII = Raking and removal of all forest floor.

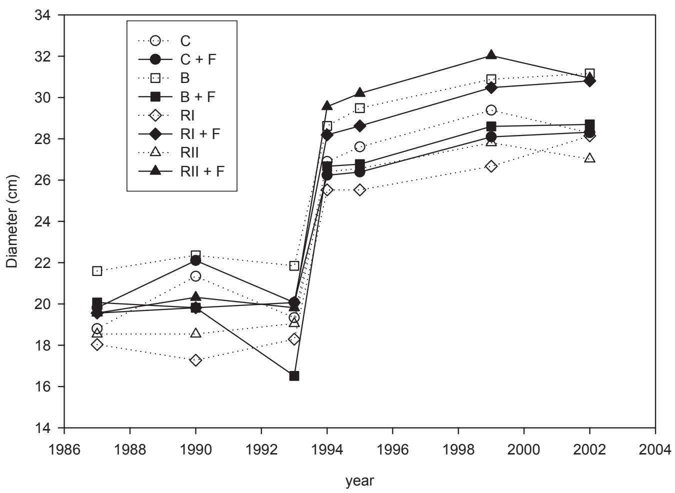

Figure 3—Mean annual diameter (cm) growth increments of mid-rotation longleaf pine. C = Control, F = Fertilization treatment, B = Prescribed winter burn, RI = Raking and removal of fresh pine litter, RII = Raking and removal of all forest floor.

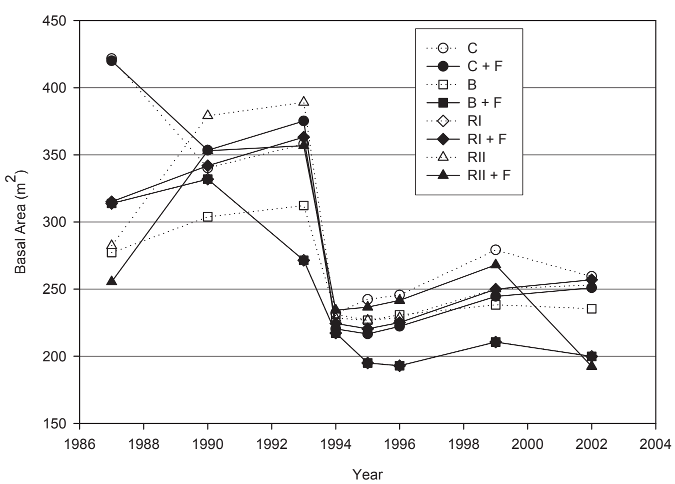

Figure 4—Mean annual basal area growth increments (m^2) of mid-rotation longleaf pine. C = Control, F = Fertilization treatment, B = Prescribed winter burn, RI = Raking and removal of fresh pine litter, RII = Raking and removal of all forest floor.

There were no consistent significant main plot treatment or interaction effects, including year, on incremental HT, DBH, or BA values for any yearly measurement period, although the fertilization treatment plots generally had higher incremental DBH and BA values than the non-fertilized treatment plots (table 2). There was a significant effect of fertilization and burn * fertilization interaction on incremental HT only in 1999 (data not shown).

From 1997 until 2001, litter production was significantly affected by litter removal, fertilization, and their interactions (table 3). Yearly litter production was always higher in the control plots when compared to litter removal plots with the same fertilization treatment. Mean annual litter production was generally the lowest in 1999 across all treatments, including controls. Fertilization almost always increased litter production compared to non-fertilized plots. Over the 5-year period (1997–2001), fertilization increased total litter production over all treatments by 22 percent compared to non-fertilized treatment plots.

There were no significant differences of litter N and P concentrations between litter raking or burning treatments, although there were significant differences in litter N and P concentrations between fertilization treatments when examined over the final 3 years of the experiment including a fertilizer * year interaction (tables 4 and 5). Fertilization increased N concentration in litter by over 20 percent over the final 3 years of the experiment compared to non-fertilized removal treatments. Phosphorus concentration in litter was significantly greater on non-fertilized plots than on fertilized plot for years 2000 and 2001.

Forest Floor and Mineral Soil

The mass of the forest floor was reduced by the litter raking and burning when compared with control treatments (table 6). No significant effect of fertilization was observed. After five 3-year cycles of burning, litter raking, and fertilization, forest floor mass was reduced by over 80 percent on burned plots, over 70 percent on Rake I plots, and more than 90 percent on Rake II plots when compared to control treatments.

Chemical analyses of the mineral soil indicated that, except for N, there were no significant treatment effects on soil nutrients (table 7) at the end of the study period. Percent soil N was significantly ($p = 0.0426$) higher in the fertilized plots. Percent Ca was significantly ($p = 0.0286$) higher in the burned treatment plots when compared to the Rake I treatment plots. Values for pH were significantly higher in the burned plots than either the control or Rake II plots while the control plots were significantly lower than the Rake I treatment. Soil organic matter concentration, averaged by main plot treatment effect, was smallest, but not significantly different, in the control treatment when compared to other treatments.

Table 2—Incremental (inc.) measurements of height (HT), diameter at breast height (DBH), and basal area (BA) after thinning in 1993 over each treatment cycle

	Main plot treatments			Split-plot fertilization treatments		
Measurement	Trt	Mean[a]	Pr > F	Trt	Mean[a]	Pr > F
		feet			*feet*	
HT inc. 1995 (1995–1993) 3 years	C RI RII B	2.8 2.7 2.1 1.7	0.8502	No Fert Fert	2.7 2.0	0.0542
HT inc. 1999 (1999–1996) 3 years	RII C B RI	3.1 3.0 2.8 2.6	0.9645	Fert No Fert	3.2 a 2.5 b	0.0032
HT inc. 2002 (2002–2000) 3 years	C RII RI B	1.3 1.0 0.7 0.1	0.7270	No Fert Fert	1.0 0.5	0.4782
DBH inc. 1995 (1995–1993)	RII C RI B	0.22 0.22 0.15 0.14	0.7579	Fert No Fert	0.19 0.17	0.7896
DBH inc. 1996[b]	B RI C RII	0.17 0.16 0.10 0.09	0.4243	Fert No Fert	0.15 0.11	0.4305
DBH inc. 1999 (1999–1996)	C RII B RI	0.55a 0.52ab 0.46ab 0.43b	0.0339	Fert No Fert	0.56 0.42	0.1139
DBH inc. 2002 (2002–2000)	RI C RII B	0.15 0.09 -0.01 -0.02	0.2668	Fert No Fert	0.08 0.03	0.613
BA inc. 1995 (1995–1993)	RII C B RI	0.031 0.025 0.019 0.015	0.6121	Fert No Fert	0.024 0.020	0.5517
BA inc. 1996[b]	B RI C RII	0.021 0.020 0.013 0.001	0.3614	Fert No Fert	0.019 0.013	0.3777
BA inc. 1999 (1999–1996)	C RII B RI	0.067 0.067 0.057 0.054	0.2220	Fert No Fert	0.071 0.052	0.0831
BA inc. 2002 (2002–2000)	RI C RII B	0.019 0.013 -0.001 -0.004	0.1859	Fert No Fert	0.011 0.002	0.4805

Note: Mean values within column with same letter are not significantly different ($\alpha < 0.05$).
[a] Data are presented in decreasing values.
[b] Additional DBH and BA measurements were taken in 1996 and are included above.
Trt = Treatment
C = Control
B = Prescribed winter burn
RI = Raking and removal of fresh pine litter
RII = Raking and removal of all forest floor
Fert = Fertilized
No Fert = Non-fertilized

Table 3—Annual litter fall (pounds per acre, kg/ha) for 1997–2001 by treatment

Treatment	1997		1998		1999		2000		2001		Totals across years	
	lbs/ac	*kg/ha*	*lbs/ac*	*kg/ha*	*lbs/ac*	*kg/ha*	*lbs/ac*	*kg/ha*	*lbs/ac*	*kg/ha*	*lbs/ac*	*kg/ha*
C	2,968 ab	3327	2,896	3246	2,824	3166	2,600 ab	2915	3,933 ab	4408	15221	17062
C + Fert	3,819 a	4281	3,331	3732	2,571	2881	3,197 a	3583	4,467 a	5007	17385	19484
B	2,231 ab	2501	2,137	2395	1,079	1209	1,974 b	2212	2,660 ab	2982	10081	11299
B + Fert	3,389 ab	3798	2,589	2902	1,358	1523	1,708 b	1914	3,578 ab	4010	12622	14147
Rake I	1,875 b	2102	1,969	2207	1,122	1257	2,171 ab	2433	2,442 b	2737	9579	10736
Rake I + Fert	3,705 ab	3032	2,896	3246	2,141	2400	2,718 ab	3046	4,134 ab	4633	15594	16357
Rake II	2,362 ab	2647	2,360	2645	1,207	1353	2,412 ab	2704	2,745 ab	3076	11086	12425
Rake II + Fert	3,370 ab	3777	3,105	3481	2,108	2363	2,547 ab	2854	3,301 ab	3700	14431	16175

Note: Mean values within column with same letter are not significantly different ($\alpha < 0.05$).
C = Control
B = Prescribed winter burn
RI = Raking and removal of fresh pine litter
RII = Raking and removal of all forest floor
Fert = Fertilized
No Fert = Non-fertilized

Table 4—Litter fall nitrogen (N) and phosphorus (P) concentrations taken during the final 3-year cycle of treatments

	1999	2000	2001	1999	2000	2001
Treatment		**Nitrogen**			**Phosphorus**	
		---------- *percent* ----------			---------- *parts per million* ----------	
C	0.24	0.33	0.18	191.9	299.7	388.1
C + Fert	0.31	0.42	0.23	288.7	251.2	292.7
B	0.23	0.35	0.18	255.3	407.3	481.4
B + Fert	0.32	0.43	0.25	312.2	316.4	311.1
Rake I	0.22	0.32	0.14	191.4	334.6	416.8
Rake I + Fert	0.27	0.41	0.21	291.1	249.6	273.6
Rake II	0.22	0.30	0.17	328.1	366.8	470.3
Rake II + Fert	0.30	0.42	0.25	236.8	287.8	324.1
All treatments		**Nitrogen**			**Phosphorus**	
		---------- *percent (mean)* ----------			---- *parts per million (mean)* ----	
No Fert	0.23 a	0.33 a	0.17 a	241.6	352.1 a	439.2 a
Fert	0.30 b	0.42 b	0.23 b	282.2	276.2 b	300.4 b

Note: Mean values within column with same letter are not significantly different ($\alpha < 0.05$).
C = Control
B = Prescribed winter burn
RI = Raking and removal of fresh pine litter
RII = Raking and removal of all forest floor
Fert = Fertilized
No Fert = Non-fertilized

Table 5—P-values of treatment impacts on litter fall nitrogen (N) and phosphorus (P) concentrations taken during the final 3-year cycle of treatments

Factor	Nitrogen	Phosphorus
	---- P-values ----	
Litter removal trt	0.1971	0.3058
Fert trt	<0.0006	0.0209
Litter removal trt * Fert trt	0.6947	0.3470
Year	<0.0001	<0.0001
Litter removal trt * Year	0.6968	0.3470
Fert trt * Year	0.1809	<0.0001
Litter removal trt * Fert trt * Year	0.8680	0.1549

Trt = Treatment
Fert = Fertilization

Table 6—Calculated mass and nutrient content (pounds per acre, kg/ha) in H and F layers from 2002 samples

Treatment	Mass	Mass	Carbon	Carbon	Nitrogen	Nitrogen
	lbs/ac	*kg/ha*	*lbs/ac*	*kg/ha*	*lbs/ac*	*kg/ha*
C	17,196.8 a	19 275.1	7,436 d	8334	140 d	157
C + Fert	15,277.0 a	17 123.0	9,102 d	10 201	190 d	213
B	2,285.0 b	2561.2	1,396 b	1565	18 b	20
B + Fert	3,455.7 b	3873.3	1,277 b	1431	20 b	22
Rake I	2,781.9 b	3118.1	2,373 b	2660	36 bc	40
Rake I + Fert	6,322.7 ab	7086.8	3,306 c	3706	55 c	62
Rake II	1,299.9 b	1457.0	581 a	651	8 a	9
Rake II + Fert	480.5 b	538.6	147 a	165	2 a	2

Note: Mean values within column with same letter are not significantly different ($\alpha < 0.05$).
C = Control
B = Prescribed winter burn
RI = Raking and removal of fresh pine litter
RII = Raking and removal of all forest floor
Fert = Fertilized
No Fert = Non-fertilized
H = Humus
F = Fresh litter

Table 7—Properties of the 0- to 2-inch (0- to 5-cm) soil depth, measured in 2001 under a mid-rotation longleaf pine stand with a 3-year cycle of litter removal, burning, and fertilization

Treatment	Acidity	OM	C	N	P	K	Ca	Mg
	pH	----------------------------------			%		----------------------------------	
C	4.30	0.95	0.89	0.009	3.30	3.2	4.8	1.2
C + Fert	4.35	0.80	0.71	0.011	4.25	2.0	7.1	1.6
B	4.80	1.15	2.92	0.014	5.75	3.1	10.3	1.8
B + Fert	4.60	1.15	1.00	0.018	4.85	2.2	8.9	1.7
Rake I	4.60	0.95	0.64	0.011	4.15	2.0	4.9	1.1
Rake I + Fert	4.50	1.15	0.95	0.018	3.35	3.6	5.9	1.2
Rake II	4.30	1.25	1.01	0.016	3.50	4.2	7.5	1.6
Rake II + Fert	4.25	1.15	0.98	0.018	3.50	2.9	7.2	1.7
Average by main plot treatment effect								
C	4.33b	0.88	0.71	0.010	3.78	2.6	5.9 a	1.4
B	4.70 a	1.15	0.95	0.016	5.30	2.7	9.6 a	1.7
Rake I	4.55 a	1.05	0.08	0.014	3.75	2.8	5.4 b	1.1
Rake II	4.27 b	1.20	1.00	0.017	3.50	3.5	7.4 a	1.6
Fert	4.43	1.06	0.91	0.016 a	3.99	2.7	7.3	1.5
No Fert	4.50	1.08	0.82	0.012 b	4.18	3.1	6.9	1.4

Note: Mean values within column with same letter are not significantly different (α < 0.05).
C = Control
B = Prescribed winter burn
RI = Raking and removal of fresh pine litter
RII = Raking and removal of all forest floor
Fert = Fertilized
No Fert = Non-fertilized
OM = Soil organic matter

DISCUSSION

Concerns regarding pine straw raking generally revolve around potential impact on tree growth and long-term productivity due to nutrient removal and potential soil disturbance. In this experiment, there were no significant raking or fertilizer treatment effects on either total or incremental height, diameter, or BA. The large increase in diameter and heights between 1993 and 1994 is attributed to a growth response to the thinning. There was a singular significant difference within 1995–1999 DBH incremental analysis, and although there appeared to be trends in the data overall, there were no statistically significant effects of raking or burning on growth of the stands (table 2), perhaps, in part, due to there being only two blocks. However, these results are in line with findings of Haywood (2009) and work done previously on the site by Ross and others (1995).

Overall, there were no consistent significant main treatment effects or trends in litter production. Generally higher litter production in the fertilized control plots compared with all other plots is consistent with other findings (McLeod and others 1979, Ross and others 1995). Comparison of the litter removal treatments with the controls shows that in a majority of the sample years the fertilized treatment plots produce the same or more litter than the unfertilized controls. This indicates that the addition of fertilizer can be used to ameliorate nutrient loss from frequent litter raking and prescribed burning. The significantly higher P concentrations in the non-fertilized treatments are contrary to other findings (Haywood 2009, Haywood and others 1998), but are supported by soil analysis results (table 7).

CONCLUSION

These results are consistent with earlier work and show the important role that the forest floor plays in storing and cycling nutrients. In this study, litter removal decreased litter production and forest floor mass. Fertilization was partially able to compensate for this decrease in litter mass and removal of nutrients. Soil chemistry remained largely unchanged by litter removal, except where burning of the litter layer released nutrients into the soil and increased measured concentrations of N, P, Ca, and Mg. Results indicate that frequent removal of the forest floor does not have a detrimental effect on longleaf pine tree growth but may reduce litter production. Nitrogen and P lost with frequent raking can be replaced with fertilization.

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Abstract: Removal of forest floor litter by pine needle raking and prescribed burning is a common practice in longleaf pine (Pinus palustris Mill.) stands on Coastal Plain sites in the Southeastern United States. Repeated removal of litter by raking and the loss of surface organic matter from controlled burns can affect the already low fertility of these sites. Although fertilization may compensate for some nutrient losses, long-term changes in soil chemical properties may still negatively affect productivity. In this experiment, we continue work that examined the effect of burning, fertilization, and moderate and intensive litter raking on tree growth, litter production, and soil chemistry in longleaf pine stands over 6 years. This report discusses treatment response 9 years after selective thinning was initiated in a longleaf pine plantation in Aiken County, SC. Litter raking treatments, when compared to the control treatment, did not significantly affect tree height or basal area growth, although averages were larger in the fertilized litter raking treatments when compared to the non-fertilized litter raking treatments. However, longleaf pine litter production declined by up to 30 percent in both burned and raked treatments without fertilizer application compared to the unfertilized control. Fertilization significantly increased litter production on control plots, and it appeared to mitigate the reductions in needle fall on burned and raked plots. Soil nitrogen concentrations increased on fertilized and unfertilized burned and raked treatments when compared to the corresponding control. Results indicate moderate fertilization can sustain long-term litter removal and maintain soil nutrients in longleaf pine stands.

Keywords: Burning, fertilization, longleaf pine, raking, site response.