United States
Department of
Agriculture

Southeastern Forest
Experiment Station

Forest Service

Research Paper
SE-234

CHANGES IN SOIL FERTILITY FOLLOWING PRESCRIBED BURNING ON COASTAL PLAIN PINE SITES

ACKNOWLEDGMENTS

Samples for this study were collected from established sites of ongoing studies requiring resources from private companies, universities, and the Forest Service. Specific appreciation is expressed to William D. Boyer, USDA Forest Service, Southern Forest Experiment Station, for permission to sample the Alabama site; Dale D. Wade, USDA Forest Service, Southeastern Forest Experiment Station, for permission to sample the Florida site; E. R. Andrulot, School of Forestry, Louisiana Tech University, Ruston, Louisiana, and Georgia Pacific Corporation for permission to sample the Louisiana site; and O. G. Langdon, USDA Forest Service, Southeastern Forest Experiment Station, and Westvaco Corporation for permission to sample the South Carolina site.

June 1982
Southeastern Forest Experiment Station
Asheville, North Carolina

Changes in Soil Fertility Following Prescribed Burning on Coastal Plain Pine Sites

by

William H. McKee, Jr., Soil Scientist
Southeastern Forest Experiment Station
Charleston, South Carolina

Abstract.--Soil and forest floor samples were collected from four prescribed burning studies in the Atlantic and Gulf Coastal Plains. The surface textures of soils ranged from sands to silt loams and the drainage classes from well to poorly drained. Burning treatments had been in force from 8 to 65 years. Reduction of the forest floor and its chemical constituents was related to frequency of burning; however, a protective organic horizon remained on all soils. Burning was found to have had no deleterious effect on organic matter or nitrogen in surface mineral soil. A comparison of earlier results with present findings suggests that annual winter burning may increase nitrogen in surface mineral soil while annual summer burning appears to reduce the total nitrogen content. Prescribed burning consistently increased the amount of available phosphorus. Fractionation of soil phosphorus indicated that burning resulted in the deposition of no specific form of phosphorus but accelerated the mineralization and cycling of the nutrient. Without burning, 50 to 60 percent more calcium accumulated in the forest floor and a correspondingly lower amount in the surface 10 to 16 cm of mineral soil. It is postulated that without burning, immobilization of calcium in the forest floor can lead to nutrient imbalance and accelerated soil weathering over a long period.

Keywords: Forest soils, forest floor mineral cycling, soil development, *Pinus palustris*, *P. elliottii*, *P. taeda*, phosphorus fractions.

Prescribed burning is recognized as one of the most effective and economical tools for silvicultural management of southern pine. Burning maintains pine as a monoculture in the ecological succession and suppresses the hardwood understory (Cooper 1971; Langdon 1971). Because fire destroys organic matter and is known to volatize appreciable quantities of nitrogen, nutrient loss and possible effects on site quality have been a concern in the use of prescribed fire.

Studies on nitrogen volatilization indicate that 30 to 112 kg/ha of nitrogen may be lost with prescribed burning of southern pine stands, depending on the nitrogen content of the litter, amount of litter burned by the fire, and burning intensity (Curtis and others 1977; Wells 1971). Analysis of soils under pine stands suggests that burning increases nitrogen fixation. After a portion of the litter is removed from these sites by fire, frequently the herbaceous vegetation contains a large portion of native leguminous plants (Lewis and Harshbarger 1976) which increases soil nitrogen. Jorgensen and Wells (1971) reported that prescribed burning increases nitrogen fixation by soil microorganisms on wet sites. Studies of Coastal Plain soils indicate that total nitrogen content is not drastically reduced by burning but that its availability may be decreased (Wells 1971). Long-term results of burning on different Coastal Plain soils have not been determined (Wells and others 1979).

Phosphorus is frequently deficient on many Coastal Plain pine sites (Pritchett 1979). As indicated by Wells and others (1979), how prescribed burning affects phosphorus chemistry of forest soils is not known, although it is known that burning tends to increase "available phosphorus" in surface soil. The change in mineral soil pH and soluble cations after burning may produce a long-term effect on phosphorus solubility.

The release of cations in forest litter after burning has been well documented (Heyward and Barnette 1934; Metz and others 1961; Wells 1971), and an increase in pH noted. Neither the duration of this pH change after prescribed burning nor the effects of cation release for differently textured soils are well documented. Examples of where calcium, potassium, or magnesium additions to southern pine on undisturbed Ultisols resulted in increased growth could not be found in the literature. Pritchett (1979) indicated that these elements are seldom deficient in forest sites.

Besides the obvious effect of fire on mineral release, a long-term effect on soil weathering and development may result from prescribed burning. Herbauts (1980) reports evidence that, in slightly podzolized soils, amorphous oxides and cations from the surface mineral soil are leached by organic acids from the forest floor. Burning markedly reduces the level of organic matter in the forest floor (Curtis and others 1977). The remaining organic matter in the form of "charcoal" or partly charred material is less water soluble than the original litter and, thus, may serve as cation exchange material in surface mineral soil (Wells and Davey 1966).

The objectives of this study were (1) to determine the effect of prescribed burning on the nutrient content in the forest floor after 8 to 65 years, and (2) to determine changes in chemical forms of phosphorus and concentrations of other nutrients in the surface mineral soil on a range of Coastal Plain pine sites.

MATERIALS AND METHODS

Established prescribed burning studies which comprise a range of soil textures, drainage classes, topographic positions, and understory vegetation were selected in the Coastal Plain for study. None of the studies sampled had a detailed soil analysis before the burn treatments; however, interim burning effects were reported for two of the studies (Heyward and Barnette 1934; Metz and others 1961; Wells 1971). Brief descriptions of the four areas sampled follow.

Study Areas

Alabama.--This study is located on the Escambia Experimental Forest near Brewton, Alabama, on upper Coastal Plain terrain. Soils on the study area are classed as Benndale (Typic Paleudult, coarse loamy siliceous thermic), complexed with Orangeburg (Typic Paleudult, fine loamy siliceous thermic), Troup (Grossarenic Paleudult, loamy siliceous thermic), and Saffell (Typic Hapludult, loamy skeletal siliceous thermic). Overstory vegetation consists of 60- to 70-year-old longleaf pine (*Pinus palustris*). The stand had been thinned to prescribed basal areas at the beginning of the study. Site index (age 50) ranged from 19 to 24 m on these soils. Understory vegetation consists of grasses, forbs, and small woody sprouts. Large hardwoods were removed initially. Numerous small, hardwood sprouts had reestablished themselves on the control plot.

Plots were 0.16 ha with eight replicated blocks. Treatments sampled were no-burn control and a biennial winter burn. The study was initiated in 1970, and the burn plots had been subjected to five fires. The last winter burn was applied approximately 4 months before sampling.

Florida.--This study is located on the Osceola National Forest in north-central Florida flatwoods on level Coastal Plain terrain. Soil on the study area is classed as Leon, sand (Aeric Haplaquod, sandy siliceous thermic) with an organic pan between 46 and 61 cm deep. The overstory vegetation contains mixed, naturally seeded longleaf and slash (*P. elliottii*) pines 60 to 70 years old. Site index (age 50) for the study area is 20 m, and average basal area is approximately 15.3 m^2/ha. Understory vegetation consists largely of saw-palmetto (*Serenoa repens*), gallberry (*Ilex glabra*), runner oak (*Quercus pumila*), blueberry (*Vaccinium* spp.), lyonia (*Lyonia lucida*), wiregrass (*Aristida* spp.), and broomsedge (*Andropogon* spp.). Cattle are grazed on the study area and may have altered understory vegetation.

Plots are 0.81 ha with six replications in a randomized block design. Treatments consist of no-burn control, periodic winter burn (every 4 years), and annual winter burn. The annual winter burn was not imposed until 6 years after initiation of the study; at the time of sampling, there had been 14 burns.

Louisiana.--This study is located in north-central Louisiana on a middle Coastal Plain site near the town of Urania on land owned by Louisiana Pacific Corporation. This study, 65 years old at time of sampling, has been frequently referred to in the literature as the "Roberts Plots." Soil is classed as Frizzel (Glossaquic Haplundalf, coarse-silty siliceous thermic). Previous reports on the study have referred to the soil series as a Montrose silt loam (Murad and others 1979). A detailed description of vegetation on the plots is also given by Murad and others (1979). Overstory vegetation consists of a 65-year-old longleaf pine stand established from a natural seedfall. Understory vegetation consists of bluestem grass (*Andropodon* spp.) on the burn plot and hardwood trees of 10 to 15 cm d.b.h. on the unburned control plot. Basal area for the stand is estimated to be about 18 to 20 m^2/ha.

Plots are approximately 0.10 ha. Treatments consist of a no-burn control and an annual winter burn with no replication. Eleven months before sampling, a wildfire burned the control plot at a fairly high intensity and may have had a pronounced effect on some chemical properties measured. This was the only wildfire to burn the control plot in the 65-year study. Throughout the study, burning treatments have been intense headfires, while burns imposed on the other three study areas generally have been backfires or flank fires.

South Carolina.--This study is located in eastern South Carolina on a Pleistocene terrace of the lower Coastal Plain. The terrain is nearly level and is poorly to somewhat poorly drained. Soils are described as Bayboro (Umbric Paleaquult, clayey mixed thermic), Bladen (Typic Albaquult, clayey mixed thermic), Coxville (Typic Paleaquult, clayey kaolinitic thermic), Dunbar (Aeric Paleaquult, clayey kaolinitic thermic), Duplen (Aquic Paleudult, clayey kaolinitic thermic), Goldsboro (Aquic Paleudult, fine-loamy siliceous thermic), and Lynchburg (Aeric Paleaquult, fine-loamy siliceous thermic). The overstory is 70-year-old loblolly pine (*P. taeda*) with a site index (age 50) of 27 to 30 m. Understory vegetation varies drastically with the burn treatment and has been documented by Lewis and Harshbarger (1976). Burning treatments were begun 30 years prior to the current sampling.

Plots are 0.10 ha, with three replications located on the Santee Experimental Forest near Charleston and two replications located on Westvaco Corporation land near Andrews, South Carolina. Treatments consist of no-burn control, periodic winter burn, periodic summer burn, annual winter burn, and annual summer burn. Periodic burn treatments were applied nearly every 7 years, or when hardwood stems were approximately 2.5 cm d.b.h.

Soil Texture

Soil texture was measured on all plots in the study site because variations may alter retention and movement of nutrients through the mineral soil after burning.

Soil textures were found to be uniform across burning treatment plots for the Alabama, Florida, and Louisiana sites. A sand texture class was indicated for the Alabama site, with sand content from 79 to 82 percent and clay from 6 to 9 percent, and for the Florida site, with 89 to 91 percent sand and 5 to 6 percent clay. The Louisiana soil was considerably heavier, with a silt loam topsoil and a loam at 30 to 40 cm.

Mechanical analysis of the South Carolina soil indicated that texture varied with treatments. Sand content ranged from 47 to 56 percent, with greater amounts of sand on the periodic burn plots and the least amount on the annual summer burn plots for the 0- to 5-cm soil layer. The same relationship is found for the 5- to 10-cm layer, with sand averaging 51 percent. On the 15- to 20-cm layer, which generally represents the A2 horizon, sand ranged from 39 to 50 percent, with the control and annual summer burn plots having less sand than did other plots. Sand averaged 36 and 33 percent in the lower two soil layers.

Clay content was higher by 4 to 5 percentage points on the annual winter burn plots than on the control or periodic burn plots. Clay averaged 19 percent in the 5- to 10-cm soil layer, which indicated 6 to 7 percentage points higher clay levels on the control and annual summer burn plots than on the periodic winter burn plots. Clay averaged 38 percent in the 30- to 35-cm layer and 41 percent in the 45- to 50-cm layer, where the lower layer represents the B21t or B22t portion of the soil profile. Because of the apparent texture variation among burning treatments in the South Carolina study, texture is used as a covariant to compute total nutrient content on an area basis. The use of this covariant results in an improved test of treatment effects because it is assumed that the 30 years of prescribed burning did not alter texture and that the exchange capacity, organic content, and cation concentration are related to texture.

Sampling Methods

Each plot in the four studies was sampled at 40 points, with 10 sample points composited to make 4 samples per plot for each forest floor layer or soil horizon. Samples consisted of all material including L, F, and H layers collected from within a 15-cm square frame. The forest floor was mor humus that has little mixing with the mineral soil. No attempt was made to segment the forest floor by layers.

Two 2.5-cm soil cores were collected from within the square sample point. The cores were segmented into centimeter depths of 0 to 5, 5 to 10, 15 to 20, 30 to 35, and 45 to 50 on the South Carolina and Louisiana plots, and 0 to 8, 8 to 16, and 32 to 40 on the Alabama and Florida plots. The 0- to 5- and 5- to 10-cm sample depths represent the A1 horizon on the heavier soils and correspond to sampling depths made previously on these sites. The 15- to 20-cm depth represents the A2 horizon over the range of heavier soils. The 30- to 35- and 45- to 50-cm depths were selected to sample the B1 and upper B2 horizons. On the sandier soils, the 0- to 8-cm sample represents the A1 horizon. Because more movement of nutrients was expected on these sites, depth was increased to measure the burning response. The 8- to 16- and 32- to 40-cm depths represent the A2 horizon on these sites and were the lowest depths on which a measurable burning effect was expected.

Laboratory Methods

Forest floor samples were dried at 70° C for 24 h, weighed, and ground to pass a 40-mesh screen. Nitrogen was determined with a modified micro-Kjeldahl procedure with 0.1 g of material digested in a test tube, and ammonia was determined by the salicylate-cyanurate procedure (Nelson and Sommers 1973). Other analyses were made on material dry ashed for 2 h at 450° C and taken up in 0.03 N HNO_3. Phosphorus was determined by the molybdovanadate procedure (Jackson 1958); potassium, calcium, and magnesium were determined by atomic absorption. A separate sample was dry ashed at 500° C for 2 h to determine mineral content, which was subtracted from the dry weight; thus, weights of forest floor material represent only loss on ignition component.

Soil samples were air dried and crushed to pass a 2-mm sieve. Organic matter content was assayed by wet oxidation (Jackson 1958), and particle-size distribution was determined by the hydrometer method (Day 1965). Exchangeable bases were determined by atomic absorption on extracts made with 1N NH_4OAC (Jackson 1958). Available phosphorus was determined by extracting 2.5 g of soil with 20 ml of Bray P2 solution (Bray and Kurtz 1945). Inorganic phosphorus was fractionated by the method of Chang and Jackson (1957), and organic phosphorus was determined by the procedure outlined by Olsen and Dean (1965) on samples with centimeter depths of 0 to 5 or 0 to 8. Total soil nitrogen was determined by micro-Kjeldahl digestion of a 1.0-g sample, and ammonia was determined by the salicylate-cyanurate method (Nelson and Sommers 1973). Soil pH was measured with a glass electrode on a 1:2 soil: water mixture.

Results are expressed as nutrient concentrations in soil components and as total content in surface soil and forest floor. Bulk density values are from previous measurements taken on the South Carolina study (Ralston and Hatchell 1971) and from typical profile properties of soil series involved on other sites (USDA SCS 1975-1980). Comparison of burning treatments within studies is made by analysis of variance, with significant differences reported at the 0.05 level.

RESULTS AND DISCUSSION

Mineral Soil Properties

Burning effects tended to be consistent over the range of Coastal Plain soils examined, with the degree of response reflecting soil properties of specific sites (table 1).

pH.--Soil pH increased slightly but significantly with degree of burning in the surface 0-8 or 0-5 cm layer on the Olustee and Santee burn studies. On the Olustee site, soil pH was 0.14 unit higher on the annual burn than on the periodic burn plots. On the South Carolina site, soil pH was significantly higher on the annual summer burn plots than on control or periodic winter plots by 0.4 unit. Periodic summer and annual winter burn plots had intermediate pH values which did not differ significantly from those on other treatments. On the Alabama site, prescribed burning did not significantly alter pH values; however, on burned areas, treatments averaged 0.2 to 0.3 pH units higher. At lower depths, burning had no apparent effect on soil pH values as measured in this study.

For a wide range of soils and burning techniques, soil pH has been shown to increase to some degree shortly after burning (Wells and others 1979). Normally, acidity increases with time after burning and soil pH returns to its preburning value. Degree of pH increase and time needed to return to the preburning level depend on burning intensity, amount of forest floor consumed, soil properties (including organic matter and clay content), rainfall, and internal soil drainage. Findings in this study indicate that periodic burn treatments had averaged pH values slightly higher than those of the control plots, demonstrating that pH increase following a burn is apparent for at least 7 years on heavier soils. The pH value for the periodic burn treatments on the sandy Florida soils did not differ from that of the unburned control, which suggests that pH increase had a shorter duration on this site--last burned 2 years before sampling.

Table 1.--Available nutrients and physical properties of mineral soil layers following prescribed burns on four study areas

Soil depth and burn treatment	pH	Total N	Avail. P	Exchangeable bases				Sand	Clay	Organic content
				K	Ca	Mg	Na			
		- - - - - p/m - - - - -		- - - - meq/100 g - - - -				- - - percent - - -		
				BREWTON, ALABAMA						
0-8 cm										
Control	5.2	635	2.3	0.05	1.27B	0.20A	0.10	82	6	2.28
Biennial winter	5.4	770	2.4	.04	1.89A	.14B	.10	81	6	2.69
8-16 cm										
Control	5.4	377B	1.7	.02	.84	.08	.09	82	7	1.43
Biennial winter	5.4	483A	1.9	.02	1.10	.10	.09	81	7	1.37
32-40 cm										
Control	5.4	226	1.0	.02	.67B	.09	.09	81	7	1.00
Biennial winter	5.4	247	1.2	.02	.80A	.12	.09	79	9	.85
				OLUSTEE, FLORIDA						
0-8 cm										
Control	4.1AB	1,028B	7.05B	.03	.25B	.22B	.09	89	6	3.72B
Periodic winter	4.0B	1,213AB	9.55A	.04	.45A	.35A	.10	89	6	4.81A
Annual winter	4.2A	1,317A	10.48A	.04	.57A	.38A	.08	88	6	4.55AB
8-16 cm										
Control	4.5	412	3.11	[a] .01A	.14	.08	.05A	91	5	1.48
Periodic winter	4.4	368	3.15	.01B	.15	.09	.04B	91	5	1.60
Annual winter	4.4	401	3.87	.01B	.15	.09	.03C	91	5	1.46
32-40 cm										
Control	4.8	315	8.94	.01A	.10	.04	.04A	91	5	1.17
Periodic winter	4.9	342	5.92	.00+B	.07	.04	.04A	91	5	1.07
Annual winter	4.9	428	7.56	.00+B	.06	.03	.03B	91	5	1.39
				ROBERTS PLOTS, LOUISIANA[b]						
0-5 cm										
Control	5.2	1,165	2.84	.08	2.96	.58	.09	43	9	4.17
Annual winter	5.5	1,123	3.02	.08	2.69	.96	.11	--	--	3.36
5-10 cm										
Control	5.5	637	1.39	.05	2.38	.42	.07	34	9	2.23
Annual winter	5.3	447	1.41	.04	1.19	.56	.18	28	12	3.33
15-20 cm										
Control	5.3	403	.62	.03	1.62	.47	.07	32	15	1.78
Annual winter	5.0	302	.64	.03	.55	.56	.22	27	17	1.99
30-35 cm										
Control	5.1	408	.24	.05	2.98	.96	.07	29	23	1.73
Annual winter	4.9	371	.35	.04	.49	.80	.25	24	24	1.80
45-50 cm										
Control	5.0	443	.22	.05	1.67	1.12	.08	33	12	1.49
Annual winter	5.0	363	.21	.04	.50	.83	.31	27	25	1.67

Continued

Table 1.--Available nutrients and physical properties of mineral soil layers following prescribed burns on four study areas--continued

Soil depth and burn treatment	pH	Total N	Avail. P	Exchangeable bases K	Ca	Mg	Na	Sand	Clay	Organic content
	- - - - - p/m		- - - - -	- - - - meq/100 g			- - - -	- - - percent		- - -
SANTEE EXPERIMENTAL FOREST, SOUTH CAROLINA										
0-5 cm										
Control	4.1B	1,511	3.62B	0.07	0.63	0.28B	0.16	52	14	7.17
Periodic winter	4.1B	1,390	4.50AB	.07	.79	.33AB	.20	56	13	6.40
Periodic summer	4.2AB	1,695	5.02AB	.07	.87	.33AB	.19	54	17	7.72
Annual winter	4.2AB	2,221	5.45A	.09	1.23	.51A	.24	53	18	9.04
Annual summer	4.5A	1,721	4.13AB	.06	1.08	.38AB	.22	47	16	8.13
5-10 cm										
Control	4.5	705	1.41	.04	.31	.13	.14	49	19	8.00
Periodic winter	4.5	519	1.49	.04	.37	.13	.17	52	18	6.52
Periodic summer	4.6	711	1.74	.04	.45	.17	.18	55	19	8.16
Annual winter	4.2	943	1.99	.04	.45	.23	.23	50	21	9.15
Annual summer	4.6	746	1.46	.04	.54	.22	.21	49	17	9.81
15-20 cm										
Control	4.5	402	.61	.04	.39	.23	.15	39	29	1.46
Periodic winter	4.5	343	.77	.04	.37	.21	.15	50	22	1.28
Periodic summer	4.6	439	.92	.04	.41	.22	.17	49	25	1.51
Annual winter	4.4	417	.66	.03	.28	.21	.22	49	25	1.15
Annual summer	4.5	405	.70	.04	.44	.29	.22	40	28	2.18
30-35 cm										
Control	4.5	382	.19	.05	.47	.51	.17	33	40	1.14B
Periodic winter	4.5	292	.33	.05	.44	.41	.17	39	35	.78B
Periodic summer	4.6	437	.30	.05	.44	.41	.17	39	36	1.24AB
Annual winter	4.5	367	.18	.04	.35	.41	.22	34	40	.75B
Annual summer	4.4	420	.29	.04	.48	.42	.22	33	39	1.94A
45-50 cm										
Control	4.5	372	.07	.05	.54	.55	.19	30BC	44	.91B
Periodic winter	4.6	276	.11	.06	.45	.48	.19	36AB	38	.58B
Periodic summer	4.6	417	.15	.05	.40	.45	.18	37A	41	1.08B
Annual winter	4.4	382	.10	.05	.34	.45	.22	34ABC	44	.62B
Annual summer	4.4	411	.15	.05	.46	.45	.24	28C	40	1.83A

Values in columns for a given site and soil depth followed by different letters are significantly different at the 0.05 level.

[a]/Significance is based on values in the third decimal place.

[b]/Statistical analysis was not made because site does not have replication.

The pH values for surface soil following 65 years of annual burning on the Louisiana site are somewhat lower than those reported by Heyward and Barnette in 1934 (5.3 and 5.8 for the control and annual burn treatments) but similar to those reported by Murad and others (1979). These differences may result from variation in sampling season, depth of samples, and wildfire on the control plot before the last sampling. Samples collected after 10 years of burning on the South Carolina site averaged within 0.1 to 0.2 pH unit of the 30-year samples in both the 0-5 and 5-10 cm soil depths (Metz and others 1961). An exception is the annual winter plots with a pH value of 4.2, compared with 4.6 at 10 years.

Nitrogen.--In the mineral soil layers, an increase or at least no decrease of nitrogen was indicated from burning except on the nonreplicated Louisiana study, where less nitrogen was found on the burned plot. On the Alabama site, total nitrogen tended to be higher on burn plots at all depths, but the effect was significant only in the 8-16 cm depth where burning increased total nitrogen by 106 p/m. Nitrogen levels averaged 699 and 237 p/m for the 0-8 and 32-40 cm depths. On the Florida site, total nitrogen concentration was 289 p/m higher on annual burn plots, compared with the control plots in the surface layer. The periodic burn plot did not differ from plots with other treatments. At lower depths, burning had no significant effect, with total nitrogen averaging 394 and 362 p/m at 8-16 and 32-40 cm. The burn and control plots on the Louisiana site had nearly equal nitrogen content in the 0-5 cm depth, where the highest concentration was found and the greatest effect of burning is generally indicated. The control plot was consistently higher at all depths with values of 37 to 190 p/m more nitrogen. The lack of replication of this historic prescribed-burn study is unfortunate.

Nitrogen content of the Louisiana site was reported as 740 and 860 p/m in the 0-5 cm soil layer for the burned and control plots 44 years earlier (Heyward and Barnette 1934). These earlier values are 31 to 44 percent lower than those found in the present sampling, which may reflect changes caused by growth of the tree stand and by wildfire on the control plot. Variation in techniques and sampling may also affect results. However, values at lower depths for the present analysis are 16 to 26 percent higher on the unburned control and 19 to 22 percent lower on the annual burn treatment, which suggests that there has been a substantial increase in nitrogen in the 0-5 cm layer for both treatments over time.

Total nitrogen concentration was not significantly affected by burn treatments and decreased with soil depth on the South Carolina site. Values averaged 1,708, 725, 401, 380, and 372 p/m in the five layers sampled. However, nitrogen content tended to increase with burning. A comparison of results to analyses made 10 and 20 years after the study was established is made in a later section.

Available phosphorus.--The amount of available phosphorus was higher for burn treatments on all four study sites. On the Alabama site, treatment effects did not differ significantly, but phosphorus levels were 0.1 to 0.2 p/m higher on burn plots. Available phosphorus averaged 2.4, 1.8, and 1.1 p/m in the three sample depths. Annual and periodic burns increased available phosphorus by 2.5 to 3.4 p/m in the 0-3 cm depth on the Florida site. Frequency of burning had no effect. At lower depths, with average values of 3.4 and 7.5 p/m, burning treatments did not affect phosphorus content. Sampling on the Louisiana site indicated that available phosphorus was 0.03 to 0.18 p/m higher on the burn plot in the surface layer but no discernible difference was found at lower depths. On the South Carolina site, available phosphorus increased with burning where annual winter burns increased available phosphorus by 50 percent over the control. Other treatments did not differ significantly from the control or annual winter burn. Phosphorus content below the surface averaged 1.62, 0.73, 0.26, and 0.12 p/m by sample depth for the five burn treatments.

Metz and others (1961), using a Bray P_2 extractant, report phosphorus ranging from 13 to 26 p/m, but they report values of 3 to 7 p/m when using a double acid extraction after 10 years. Wells (1971) reports phosphorus as a total quantity per acre but with values in the range of the present study after 20 years. Other investigations have also indicated that burning increased available phosphorus (Wells and others 1979). The effect of burning on specific chemical forms of phosphorus is reported in a later section.

Exchangeable potassium.--Potassium levels were not altered by burning treatments and were low, by agronomic standards, on all four sites. Exchangeable potassium averaged 0.04, 0.02, and 0.02 meq/100 g in the three soil layers on the Alabama site. Higher potassium content may be present in the heavier clay subsoil underlying the surface sand on these soils. On the Florida site, the response of exchangeable potassium to treatment was similar to that of phosphorus. Either burn treatment resulted in a 0.01-meq/100 g increase. At lower depths, potassium averaged about 0.01 meq/100 g, with the control plots higher than the burn treatments. Potassium concentration would have to be carried to at least three decimal places to show this milliequivalent. Such precision is beyond the normal detection limits of the laboratory analysis. A contributing factor may be the slightly higher amount of clay on the control plots.

Exchangeable potassium was not influenced by burn treatments and averaged 0.06 to 0.09 meq/100 g in the 0-5 cm soil layer on the South Carolina and Louisiana sites. Lower soil layers had 0.03 to 0.06 meq/100 g of exchangeable potassium.

Exchangeable calcium.--On the Alabama site, burning increased exchangeable calcium in the 0-8 and 32-40 cm depths by 0.62 and 0.13 meq/100 g. The same trend is found at the 8-16 cm depth but differences are not significant. Similarly, on the Florida site the burned plots had 0.20 to 0.32 meq/100 g more exchangeable calcium than did the burn control. Calcium averaged 0.15 and 0.08 meq/100 g in the 8-16 and 32-40 cm depths over treatments.

In contrast to the other burn studies, calcium content on the Louisiana site was consistently higher on the control plot by 2.49 to 0.19 meq. Wildfire or inherent soil calcium concentration may be factors. Exchangeable calcium values reported for this site in 1934 by Heyward and Barnette were 0.19 to 1.46 meq higher than the present findings. Variations in sampling and extraction probably account more for these differences than do changes in the site from development of the tree stand.

Burn treatments did not significantly alter exchangeable calcium concentration on the South Carolina site, but calcium frequently tended to increase with increased burning in the 0-5 cm soil layer. Burning was found to significantly increase calcium for this site with the 10- and 20-year sampling (Metz and others 1961; Wells 1971). Values for exchangeable calcium 10 and 20 years after initiating burn treatments were within the range of the 30-year values and thus far do not indicate any trend over time in quantities of this nutrient in the mineral soil. Calcium averaged 0.42, 0.38, 0.43, and 0.44 meq/100 g at depths of 5 to 50 cm.

Exchangeable magnesium.--Generally magnesium responses to burning were similar to calcium responses. Exchangeable magnesium increased with burning by 0.06 meq/100 g in the 0-8 cm soil layer on the Alabama site. At lower depths, magnesium ranged from 0.09 to 0.10 meq/100 g and was unaffected by burning treatments. On the Florida site, magnesium content was 0.13 to 0.16 meq higher on the burn plots, compared with the control in the 0-8 cm soil layer. At lower depths, magnesium averaged 0.08 to 0.04 meq/100 g.

In contrast to exchangeable calcium, magnesium concentration on the Louisiana site was higher on the burn plot in the upper three sampling depths by 0.09 to 0.38 meq/100 g. At the lower two depths, the control plot had 0.16 to 0.29 meq more magnesium than did the burn plots.

The annual winter burn had 82 percent more exchangeable magnesium than did the control plot on the South Carolina site. Other burn treatments did not differ from the control or annual winter burn. Magnesium at lower depths averaged 0.18 to 0.47 meq/100 g and was not affected by burning treatment.

Exchangeable sodium.--Burning had no effect on exchangeable sodium for the Alabama, Louisiana, and South Carolina sites. Values ranged from 0.07 to 0.31 meq/100 g. On the Florida site, sodium content did not vary in the surface 8 cm of soil. At the 8-16 and 32-40 cm depths, however, ion levels were 0.01 and 0.02 meq higher on the control plots than on the annually burned plots. At 16 cm the periodically burned plots had 0.01 meq more sodium than did annual burn plots but 0.01 meq less exchangeable sodium than did the control plots.

Organic matter.--Burning tended to increase the percentage of organic matter found in the surface 0-5 or 0-8 cm depth. On the Alabama site, burning effects were not significant; however, the biennial winter burn plots had 0.41 percentage points more organic matter than did control plots. Soils averaged 2.49, 1.40, and 0.93 percent organic matter in the 0-8, 8-16, and 32-40 cm soil layers. Periodic burning increased the percentage of organic matter in the 0-8 cm soil layer by 1.09 percent over the unburned plots on the Florida site. Annually burned plots did not differ from other treatments but averaged 0.83 percent higher than the control. Organic matter averaged 1.52 and 1.21 percent at the lower depths.

On the Louisiana site, organic matter was 0.81 percentage points higher on the control plot at the 0-5 cm depth but 1.10 percentage points higher on the burn plot at the 5-10 cm depth. Organic content decreased with depth but appeared to be higher on the burn plot by 0.07 and 0.21 percentage points. Values reported by Murad and others (1979) appear lower, partially explained by a sampling difference where a greater soil depth apparently is used. Comparison of amounts of organic matter on this site is further complicated by the wildfire 11 months earlier.

On the South Carolina site, amount of organic matter reflected treatments. Annual winter burn plots had 1.32 to 2.64 percentage points more organic matter than did periodic burn or control plots for the 0-5 cm depth, but differences are not significant. The same general relationship was found at 5-10 cm. Significant differences due to treatments were observed at 30 to 50 cm below the surface, where annual summer burn plots contained significantly more organic matter than did other treatments by 0.75 to 1.25 percentage points except at 30 to 35 cm, where annual and periodic summer burns were not significantly different. The only explanation for the significant differences between treatments at these depths is that texture, drainage, and soil development may have interacted in some way to induce them.

Organic matter content observed in the 0-5 and 5-10 cm depths after 10 years (Metz and others 1961) shows a trend similar to that of the 30-year results except that values averaged 0.6 to 2.7 percentage points higher at 10 years with wet combustion. The 20-year measurements (Wells 1971) were similar to those made at 30 years for the surface 10 cm of soil. The present findings further support Wells' observation that most of the organic matter changes resulting from fire occurred in the first 10 years. Organic matter on a total weight basis is discussed in a later section.

Phosphorus fractions in the surface mineral soil.--Phosphorus was fractionated into various chemical forms in the surface 5 to 8 cm to determine the effect of prescribed burning on the disposition of phosphorus in the mineral soil and its availability for plant uptake.

The water-soluble fraction of phosphorus represented 3 to 10 percent of total phosphorus present on the Alabama, Louisiana, and South Carolina sites (table 2). The Florida site, the only one showing a significant treatment effect, contained 33 to 34 percent of total phosphorus in water-soluble form, and periodic or annual burning significantly increased this by 24 to 29 percent. Except on the Louisiana site, burning tended to increase the water-soluble fraction by a small amount. Of interest is the relatively high level of the water-soluble fraction compared to total available phosphorus. Water-soluble phosphorus is extracted with normal ammonium chloride with a wide soil-solution ratio (1:50) and a 30-min shaking time. Thus, this fraction includes considerable loosely bound phosphorus that may not dissolve with a narrow soil-solution ratio and short mixing time.

Table 2.--Distribution of phosphorus in different chemical forms in the upper soil layer following burn treatments on four study areas

Site and burn treatment	Phosphorus fraction					
	H_2O	Al	Fe	Ca	Organic	Total
	- - - - - - - - - - - -	- - - -	- - - -	p/m	- - - -	- - - - - - - - - - - -
Alabama (0-8 cm)						
Control	2.9	0.4B	6.0	2.4	20.1B	31.7B
Biennial winter	3.0	.6A	6.3	2.2	23.3A	35.3A
Florida (0-8 cm)						
Control	10.7B	1.4	2.1	1.2	18.0	33.4B
Periodic winter	13.3A	1.7	2.5	1.4	21.6	40.6A
Annual winter	13.8A	1.7	2.7	1.1	21.2	40.5A
Louisiana (0-5 cm)[a]						
Control[b]	2.4	.5	7.4	.9	25.0	36.2
Annual winter	1.7	.3	12.5	3.3	30.0	47.8
South Carolina (0-5 cm)						
Control	4.4	4.3	15.2	2.7	52.1	78.0
Periodic winter	5.5	5.3	13.9	2.7	45.8	73.3
Periodic summer	4.8	5.4	12.4	2.4	53.0	77.9
Annual winter	4.8	5.1	17.0	2.9	56.4	86.3
Annual summer	4.5	4.2	16.7	2.2	51.6	79.2

Values for chemical fractions followed by the same letter or with no letter within study areas are not significantly different at the 0.05 level.

[a] Statistical analysis was not made because site does not have replication.

[b] Wildfire 11 months earlier.

Phosphorus in the aluminum form was less than the water-soluble fraction on all but the South Carolina site. Burning increased the aluminum phosphorus in the Alabama soil by 0.2 p/m. The same trend is apparent for the Florida soil but is not significant. The heavier Louisiana and South Carolina soils show no conclusive trend.

The iron phosphorus fraction accounted for 16 to 26 percent of total phosphorus on all but the Florida site, where the iron fraction represented 6 to 7 percent of the total. Phosphorus in the iron fraction tended to increase with burn treatments but not significantly.

Calcium phosphate represents 3 to 8 percent of total phosphorus present on the four sites. With the small amounts present (1 to 3 p/m), no apparent effect from burning was found.

Organic phosphorus accounted for 50 to 69 percent of total phosphorus in surface 5 to 8 cm of soil on the four sites. On the Alabama site, burning increased organic phosphorus by 16 percent or 3.2 p/m. On other sites, an apparent increase in organic phosphorus of 3 to 5 p/m was noted, but the increase was not significant. The amount of organic phosphorus was positively related to total phosphorus extracted from soils on these sites, accounting for 86 to 94 percent of the variation between the two variables. Burning significantly increased total phosphorus (sum of the fractions collected) extracted from sandy sites in Florida by 4 to 7 p/m. No apparent difference is found between the annual and periodic burn on the Florida site. Burning also tended to increase total phosphorus on heavier soils, but the response was not significant.

The close relationship between total phosphorus and organic phosphorus in soil indicates the need to investigate this form of the nutrient and to increase its availability to higher plants.

Daughtrey and others (1973) found the release of organic phosphorus from Coastal Plain soil completely dependent on the activity of soil microorganisms in decomposing organic matter. Nutrient release with burning would accelerate the breakdown of organic matter and release of organic phosphorus to the soil solution. At least in Florida, water-soluble phosphorus decreases when organic phosphorus increases on plots burned; however, no attempt was made to determine if this is the effect of burning or later microbial breakdown. Accumulation of organic matter and organic phosphorus is probably the result of small, particulate matter being washed into the soil.

Forest Floor Properties

Organic content.--Prescribed burning predictably lowered the total weight and nutrient content on all four sites (table 3). The unburned control

Table 3.--Average weight of forest floor component following burn treatments on four study areas

Site and burn treatment	Organic content	N	P	K	Ca	Mg	Organic to N ratio
	kg/ha × 1000	- - - - - - - - -	- - - - - -	kg/ha	- - - - - -	- - - - - - - - -	
Alabama							
Control	13.86A	226A	8.7A	6.7A	67.2A	9.3A	61:1
Biennial winter	5.44B	27B	3.1B	2.9B	29.2B	3.5B	201:1
Florida							
Control	29.16A	131A	24.7A	29.1A	115.0A	21.0A	223:1
Periodic winter	9.52B	37B	6.7B	9.5B	40.0B	11.0B	257:1
Annual winter	4.54C	7B	3.0B	4.5B	19.0B	6.0B	649:1
Louisiana[a]							
Control	39.81	307	11.8	14.0	206.0	24.6	130:1
Annual winter	22.15	127	6.8	13.1	103.0	14.0	174:1
South Carolina							
Control	26.27A	408A	17.4A	19.7A	126.0A	19.0A	64:1
Periodic winter	18.46B	300B	12.1AB	13.6AB	91.0B	19.0A	62:1
Periodic summer	17.56B	277B	10.6B	9.7B	77.0B	16.0AB	63:1
Annual winter	10.48C	156C	7.2B	6.2B	52.0C	11.0BC	67:1
Annual summer	10.05C	129C	7.1B	7.8B	48.0C	6.0C	78:1

Values for a given nutrient on individual sites followed by the same letter are not significantly different at the 0.05 level.

[a] Statistical analysis was not made, and control plot was subjected to a wildfire 11 months earlier.

plots contained from 13 to 39 t/ha of organic matter. The high value for the Louisiana site would be expected to be even higher except for the wildfire on the area. Annual or biennial burning reduced the organic level of the forest floor by 44 to 84 percent on the Alabama site. Periodic burning on the Florida and South Carolina sites reduced the weight of the forest floor by 33 to 67 percent. Season of burning did not significantly affect total organic content.

Organic content of the forest floor is approximately the same for the control plot on the South Carolina site as reported 10 years earlier (Wells 1971). The forest floor contained 18.57, 26.88, and 26.27 t/ha for the 10-, 20-, and 30-year measurements on control plots (Metz and others 1961; Wells 1971). Thus, in terms of weight, the forest floor had reached an equilibrium between 10 and 20 years after initiating the study, when trees were about 45 years old. At 30 years, the forest floor contained 18 to 39 percent mineral material (determined by dry ashing the combined L, F, and H layer samples from the four studies).

On the South Carolina site, the L layer was segmented into pine, hardwood, and other partially unidentified material. The pine component increased in the litter layer from 56 to 65 percent with annual winter burning, while the hardwood component decreased from 22 percent on control plots to 6 and 12 percent on annual winter and summer burn plots. The balance of the L layer was not pine or hardwood and could not be separated.

Wells and Jorgensen (1975) found that forest floor biomass reaches its peak in loblolly plantations at about age 30 in Piedmont stands in North and South Carolina. The sites used in this study had considerably older trees with less needle production, but the loss in needles on the forest floor was probably compensated by litter from hardwoods or herbaceous species.

<u>Nitrogen</u>.--Nitrogen content in the forest floor decreased by as much as 95 percent with annual fires and 72 percent with biennial fires. Part of this nitrogen loss was from leaching water-soluble components and fine particulate from the forest floor into the soil. The forest floor of periodically burned plots had nitrogen losses ranging from 26 to 32 percent on the South Carolina site, which had not been burned for 5 years at sampling, to a 72 percent loss on the Florida site, which had been burned the previous year. Wells (1971) observed that the burning of the periodically treated plots on the South Carolina site 10 years earlier resulted in a nitrogen loss of about 112 kg/ha by volatilization. The 408 kg/ha nitrogen in the forest floor on the control appears to represent an "equilibrium" value for this nutrient under the conditions imposed by the stand and the climate (Wells and Jorgensen 1975). The other sites also represent near-equilibrium conditions except for the Louisiana site, which had been subjected to wildfire. Of interest are the nearly equal amounts of organic matter on the South Carolina and Florida sites but about a fourfold greater amount of nitrogen on the South Carolina site compared with the Florida site. The amount of nitrogen in the forest floor probably represents species and site conditions specific to each location.

The C:N ratio (organic matter:N) is a controlling factor in determining availability of nitrogen and potential decomposition of the forest floor. The ratio of organic matter to nitrogen widened by about onefold to threefold on the Alabama, Florida, and Louisiana sites following annual or biennial fires. The change was from 5 to 20 percent for the annual burns on South Carolina plots and was not noted on the periodically burned plots. An exact C:N ratio is difficult to obtain because much of the organic matter is charred after burning; however, the magnitude of change observed reflects an apparent nitrogen mobilization that cannot be explained by degree of carbon reduction. In all cases, a number of rains had fallen on all the burn plots between the time they were burned and sampled. Comparison of forest floor values on the South Carolina plots after 20 years shows a similar trend.

Heyward and Barnette (1934) observed that the L layer had a C:N ratio nearly two to three times wider than that of the F layer. Wells and Jorgensen (1975) observed a similar relationship for loblolly pine plantations in the Piedmont, where the C:N ratio of litter narrowed over time. Because it is primarily the L layer that is consumed by fire, it is surprising that burning results in a wider C:N ratio. Apparently low-intensity fires have a "mobilizing effect" on nitrogen in the F layer, which may in part account for the increased nitrogen concentration in the upper 5 to 8 cm of mineral soil. Burning may also cause some downward movement of nitrogen as a gas through a distillation effect (Tangren and McMahon 1976).

The explanation of nitrogen movement by this mechanism is supported by findings of Klemmedson and others (1962), who showed that burning accelerated nitrogen movement into the mineral soil. Light burning in ponderosa pine (P. ponderosa) stands caused movement of 12.4 kg/ha nitrogen per year into the surface 2.5 cm of mineral soil. Wells and others (1979) summarized a number of investigations which indicate that appreciable mobilization of nitrogen as well as volatilization of the forest floor occurs after burning.

Phosphorus.--The amount of phosphorus in the forest floor was reduced by 42 to 88 percent with biennial or annual burning on all four sites. Analysis indicates that most phosphorus accumulates in the surface 5 to 8 cm of soil on these areas (see table 1). Periodic burning resulted in a 39 to 73 percent decrease in phosphorus in the forest floor. On the South Carolina site, phosphorus was reduced by periodic summer burns but not by periodic winter burns. The season of periodic or annual burning did not affect phosphorus loss, and there was no significant difference between annual and periodic fires.

Potassium.--Potassium in the forest floor ranged from 6.7 to 29.1 kg/ha and was reduced by 6 to 69 percent with biennial or annual burning on the four sites. Periodic burning reduced potassium by 67 percent on the Florida site and by 51 percent for summer fires on the South Carolina site. Results of the periodic winter fire on the South Carolina site were not significantly different from those of the unburned control. Considering that 98 kg/ha of potassium were reported to be in the plantation forest floor at age 20 (Switzer and Nelson 1972), amounts in the present sampling are relatively low, which reflects the high mobility of the element.

Calcium.--Calcium in the forest floor was reduced by 50 to 92 percent with annual or biennial burning. Periodic burning did not reduce calcium significantly on the Florida site but resulted in a 28 to 39 percent reduction on the South Carolina site. Season of burning had no effect on calcium content for this site. Thus, prescribed burning accelerated the rate of calcium returned to the soil mineral system. This movement probably resulted from cations moving in the soil solution, but ash conduction may also be a factor. Wells and Jorgensen (1975) indicate that without burning, calcium loss compared to potassium or magnesium loss is slow and that after 8 years appreciable portions of the nutrient remain in the forest floor from a given year's deposition. Quantitatively, 50 percent of the magnesium from a given year's accumulated litter is lost from the forest floor in less than 1 year, while 3 years are required to obtain this degree of calcium mineralization (Jorgensen and others 1980).

Magnesium.--Amounts of magnesium in the forest floor were approximately one-fourth to one-tenth those of calcium. The mobilization of magnesium with burning appears similar to that of calcium, and 43 to 71 percent magnesium was lost from the forest floor with biennial or annual burning. Periodic burning on the Florida site reduced magnesium by 48 percent. Periodic burning and season of burning did not significantly affect the South Carolina site. Based on values reported by Wells and Jorgensen (1975) for loblolly pine in the Piedmont, the forest floor on these sites contained about one-half to one-third the magnesium in the tree biomass, and the nutrient would be expected to move out of the floor faster than calcium.

TOTAL NUTRIENT CONTENT OF STUDY AREAS

Total nutrient content of the four study areas, by treatment, is estimated for the mineral soil layers sampled, with results expressed as kilograms per hectare.

Bulk density values reported by the Soil Conservation Service (USDA SCS 1975-1980) are used to estimate the amounts of nutrients in the surface 40 to 50 cm of soil (table 4). Burning treatments appear to have had little effect on nutrients when the entire profile is considered. Total nitrogen ranged from 1,800 to 4,500 kg/ha. Higher values are associated with the heavier mineral soils on Louisiana and South Carolina sites but also represent profiles of 50 cm of soil compared to 40 on the Alabama and Florida sites. Here, amount of available phosphorus was reversed, with greater amounts on sandy soils, ranging from 25 to 38 kg/ha. The heavy soils averaged 4 to 7 kg/ha of available phosphorus. In the deeper sampled profiles, the surface 5 to 8 cm of mineral soil contained 22 to 52 kg total phosphorus, with greater amounts on the heavier soils of the South Carolina site.

Among the four sites, exchangeable potassium ranged from 25 to 135 kg/ha. Exchangeable calcium ranged from a high of 3,250 kg/ha on the Louisiana site to a low of 130 kg/ha on the Florida site. Exchangeable magnesium ranged from 40 to 670 kg/ha, with the low and the high again on the Florida and Louisiana sites. Cation levels appear to reflect soil texture changes with higher levels found with heavier soils.

Because effects of burning are not readily apparent when comparisons are based on whole-profile samples and effects are greatest in the upper lay-

Table 4.--Estimated total nutrients in mineral profile sampled for the four burning studies

Site and burn treatment	N	P	K	Ca	Mg
			kg/ha		
Alabama (0-40 cm)					
Control	1,800	32	44	770	55
Biennial winter	2,100	38	47	1,050	75
Florida (0-40 cm)					
Control	2,200	25	25	130	40
Periodic winter	2,400	28	29	140	55
Annual winter	2,800	30	29	160	55
Louisiana (0-50 cm)					
Control	4,500	6	98	3,250	670
Annual winter	3,850	7	81	3,050	615
South Carolina (0-50 cm)					
Control	3,520	4	125	700	360
Periodic winter	2,960	6	135	650	325
Periodic summer	3,700	6	126	630	295
Annual winter	3,240	5	115	570	315
Annual summer	3,680	5	115	710	320

ers, nutrient quantities are compared by using only the surface 10 to 16 cm of mineral soil and forest floor (fig. 1). A mineral soil depth of 10 cm is used for the heavier soils of the Louisiana and South Carolina sites and 16 cm for the sandy Alabama and Florida soils. Bulk density for the Louisiana soils is reported by Murad and others (1979); for South Carolina soils, by Ralston and Hatchell (1971); for Florida soils, by L. J. Metz;[1] and for Alabama, typical soil series densities as reported by the Soil Conservation Service were used (USDA SCS 1975-1980).

Organic Matter

Burning reduced the organic content of the forest floor but not in the mineral soil; in fact, though not statistically significant, an increase is observed (fig. 1). The result is a rather small total loss of carbon from the system due to burning part of the forest floor. The poorer drained soils in Florida and South Carolina appear to have higher organic content in mineral soils than those of the Alabama or Louisiana sites. Surprisingly, the Louisiana unburned plot retained a large amount of organic matter in the forest floor despite wildfire.

Nitrogen

The sandy Alabama and Florida sites show a slight increase in nitrogen in the total system with burning despite a marked loss from the forest floor after 8 to 20 years. The Louisiana plots contrasted with the other sites where 160 kg more nitrogen is found on the unburned control compared to the burn plot. Without replication and following wildfire on the control plot, no explanation for this effect is possible.

The South Carolina study had been sampled after 10 years (Metz and others 1961) and 20 years (Wells 1971). These findings, corrected by covariant analysis with clay as the covariant, are compared with current results in terms of total nitrogen in the 0-10 cm mineral soil layer and forest floor (table 5). Over the 20-year period, total nitrogen changed little in the unburned control and periodic winter burn treatments. For these treatments, the 20-year increase of 34 to 42 kg/ha represents a 4 percent change. The periodic summer burn resulted in a 128-kg nitrogen loss. The annual winter burn increased total nitrogen by 137 kg. The striking effect was in the annual summer burn plots, where there was a 362-kg nitrogen loss. Since both summer burns resulted in total nitrogen losses, summer burning apparently has a detrimental effect on the amount of nitrogen remaining in the surface mineral soil, while winter burning increases the nitrogen. The exact cause is difficult to explain but may be related to the number of nitrogen-fixing legumes that invade these treatment sites following burns (Lewis and Harshbarger 1976).

Phosphorus

Without burning, appreciable quantities of phosphorus are tied up in the forest floor on all four sites (4 to 24 kg/ha). The amount of phosphorus in the mineral soil is difficult to relate to that in the forest floor primarily because only available phosphorus was used for the comparison, and nonsoluble forms in the chemical extraction do not appear. The test for available phosphorus is apparently sensitive to the burning treatment, with increased phosphorus found after burning; however, the quantities found do not relate well to frequency of burning or comparative reductions of phosphorus in the forest floor. A standard chemical test suitable for all sites is difficult to select because of the numerous chemical forms of phosphorus present.

When phosphorus forms in the soil are compared to tree growth, another problem is apparent regarding predicted

---

[1] Personal communication. Research Triangle Park, NC: Southeastern Forest Experiment Station; 1980.

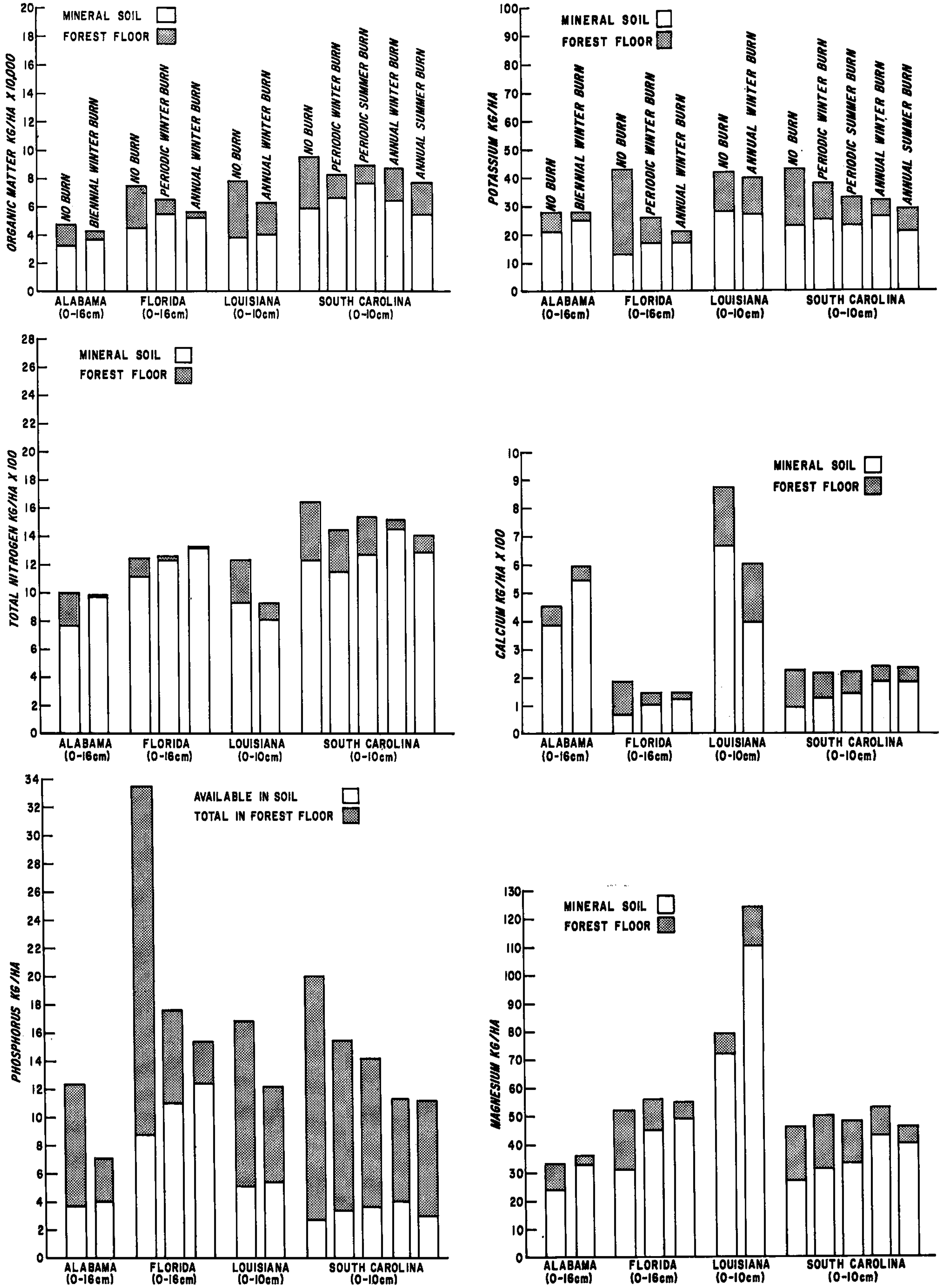

Figure 1.--Average weight of organic matter and nutrients in the forest floor and surface mineral soil on four study sites.

Table 5.--Changes in nitrogen content in the surface 10 cm of mineral soil following burn treatments in the South Carolina study

Burn treatment	10-year measurement	20-year measurement	30-year measurement	20-year gain or loss
	- - - - - - - - - - - -	kg/ha	- - - - - - - - - - - -	
Control	1,155	1,094	1,197	+42
Periodic winter	1,059	1,090	1,093	+34
Periodic summer	1,403	1,278	1,275	-128
Annual winter	1,403	1,509	1,540	+137
Annual summer	1,641	1,471	1,279	-362

long- or short-term responses, where the water-soluble fraction best defines short-term response and a "stronger acid" extraction works better for longer periods (Ballard and Pritchett 1974). The phosphorus fractions were not run on the 5-10 or 8-16 cm soil layers. Total mineral phosphorus in the 0-5 or 0-8 cm depths does not balance completely with the forest floor and in most cases does not reflect burning treatments. Prescribed burning did not consistently result in an increase in any one fraction of phosphorus in the surface mineral soil as found with available phosphorus. Rather, accumulation appears to depend on mineral, drainage, or other inherent soil factors. However, it is apparent that prescribed burning accelerates the cycling of phosphorus and benefits sites that are at least marginally deficient in the nutrient, which is significant for planning future timber rotations where phosphorus is limiting.

Potassium

The trends shown in figure 1 indicate a reduction of 12 to 20 kg/ha of potassium on the Florida and South Carolina sites as a result of burning. Other sites indicate little change. The Louisiana site may be atypical as a result of the wildfire on the control plot. Because all of these soils are characterized by weakly charged exchange sites, potassium probably cycles through a much larger portion of the profile. In addition, potassium is mobile within plants and may be retained in larger quantities in vegetation on burned plots. Thus, with potassium movement out of foliage before needle fall, this element will not be completely cycled through litter fall (Pritchett 1979).

Calcium

Except on the Louisiana site, the forest floor and 10 or 16 cm surface soil layer appear to represent a "complete cycling" of calcium in the forest floor and mineral soil system with burning treatments. Without burning, 16 to 61 percent of the calcium was in the forest floor. With burning, 4 to 16 percent of the calcium present was in the litter layer. These changes in deposition of calcium logically account for pH increases in the mineral soil associated with burning, and indicate a long-term effect on soil acidity. The amount of calcium in the forest floor decreased proportionally to the frequency of the burning in the Florida and South Carolina studies. The earlier calcium extraction in the South Carolina study (Wells 1971) showed similar results, indicating little change in the calcium status of this site in the last 10 years. In the Louisiana study, there appears to be little relationship between values reported in 1934 and present values. Earlier results indicated 565 kg/ha of calcium in the mineral soil on the unburned plot and 687 kg/ha on the annually burned plots. The earlier sampling included two additional plots (Murad and others 1979) that have since been abandoned and which may reflect differences in the two data sets.

Magnesium

In the forest floor soil system, magnesium responds similarly to calcium, where 28 to 40 percent of the magnesium remains in the forest floor without burning and 11 to 16 percent remains with annual burning. On the Louisiana site, the burn plot had less calcium but more magnesium in the forest floor and soil system. Without replication, however, it is difficult to relate this effect to the burning treatment. Values found after the last measurement on the South Carolina site appear similar to those obtained by Wells (1971) 10 years earlier.

LONG-TERM EFFECTS OF PRESCRIBED BURNING

Heyward (1937) observed that the elimination of burning on Coastal Plain pine sites resulted in abrupt change in visual characteristics in a soil profile. The interpretation is that exclusion of burning accelerates soil weathering or development. With certain moisture and parent material factors, the end result would probably be a spodosol without fire and no spodic horizon with fire. Specific reports of fire thus affecting soil formation could not be found. It appears that the natural evolutionary pattern of soil development caused by water-soluble carbon, as observed by Herbauts (1980), at least can be moderated by burning. This conclusion is based on lysimeter studies on soils under forest cover where the degree of soil weathering was found to relate to the amount of soluble carbon moving through the profile. Nutrient movement from ash material following burning is alkaline (Raison and McGarity 1978), at least until the ash has dissolved and moved into the mineral soil. To some degree, burning destroys the substrate and either consumes or volatilizes organic acids produced in the forest floor. Such change is assumed to be roughly proportional to the reduction of organic matter consumed in the burning. The water-soluble carbon has been described as humic and fluvic acid (De Kimpe and Martel 1976), carbonic acid (McColl 1971), or other soluble organic acids. Where sulfur dioxide is a problem in "acid rain" from burning fossil fuels, the resulting sulfuric acid is a much larger factor than carbonic acid (Cronan and others 1978). The acid radicals react with the soil to form salts with alkali, alkali earth, and amphoteric metals that leach through the soil horizons in the process of weathering.

Yaalon and Yaron (1966) indicate that any man-caused activity such as adding fertilizer or changing the pH will change the metapedogenetic processes that retard podsolization; the rate of change depends upon the intensity of treatments. Bidwell and Hole (1965) also discuss a series of human practices as a dominant factor in altering soil formation by controlling organic matter through prescribed burns. Thus, burning pine sites on the Coastal Plain tends to maintain soils in a less weathered state and probably in a better tilth. Historically, such has been the case for much of the Coastal Plain with the maintenance of a fire climax ecology.

Another indication of the degree of soil development or weathering is the ratio of exchangeable magnesium to calcium (Buol and others 1973). As soils become more weathered, the ratio of calcium to magnesium narrows with higher magnesium and lower calcium levels. A comparison between magnesium and calcium in the surface 5 to 8 cm of soil on the sites studied is shown in table 6. Except for the Louisiana study, the ratio of magnesium decreased with burning by 26 to 129 percent. The degree of change in the ratio appears

Table 6.--Magnesium to calcium ratio in surface 5 to 8 cm of soil after prescribed burns on four study areas

Burn treatment	Alabama	Florida	Louisiana	South Carolina
Control	0.16	0.88	0.20	0.44
Periodic winter	--	.77	--	.42
Periodic summer	--	--	--	.38
Biennial winter	.07	--	--	--
Annual winter	--	.66	.36	.41
Annual summer	--	--	--	.35

to reflect the frequency of burning in the Florida and South Carolina studies. Within the period of these studies, this effect is found only in the surface A1 horizon. Burning did not change the ratio of exchangeable magnesium to calcium at lower depths. Over an extended period, the effect of the accumulated forest floor or presence of organic acids and leaching of cations from the upper horizon--as observed by Herbauts (1980)--would appear at lower depths, including the B horizon. In any case, prescribed burning apparently slows the process of soil weathering and may help maintain soil productivity at a higher level. A final proof of this hypothesis would require a timespan approaching several hundred years.

A more immediate problem, as proposed by Lyle and Adams (1971), is a nutrient imbalance caused by higher concentrations of magnesium than of calcium. These authors observed that because of "mass action effects," magnesium in excess of calcium results in reduced loblolly pine root growth. According to this concept, the surface soil layer in the unburned Florida treatment is nearing this condition while that in the other burn treatments in this study is not. Such relationships also may be important to microbial processes found on pine sites. Predictions of long-term effects of prescribed burning on nitrogen are more difficult; however, measurements made over 20 years on the South Carolina site and 44 years on the Louisiana site indicate that winter burning may actually increase total nitrogen in the mineral soil. Regardless, there is no detectable nitrogen loss from the mineral soil except perhaps with summer fires. Several timber rotations would be required to show a pronounced effect of fire on nitrogen with the rather larger amounts of total nitrogen present (2,000 to 5,000 kg/ha) in the mineral soil.

Prescribed burning of most Coastal Plain sites will not cause a serious leaching problem for phosphorus, and the more rapid mineralization and cycling of the nutrient where it is limited will help avoid a deficiency. Potassium, because of its high mobility, probably is relatively unaffected by burning on most sites. Analysis of the sites studied over time suggests no consistent effect of burning on exchangeable potassium.

CONCLUSIONS

The most striking result of this study is the similarity of burning effects on soil properties despite obvious soil differences and probable differences in burning techniques. All the burning is reported to be low-temperature flank fires or backfires except for the Louisiana study, which--at least in early years--was reportedly burned with a headfire. The type of burn used plus wildfire that burned the control plot make observations of the Louisiana study difficult to interpret.

Organic matter consistently builds up faster in mineral soil on the burned treatments, and burning does not reduce total nitrogen except in the forest floor, where the decrease for annual burning was 280 kg/ha after 30 years in South Carolina. Total nitrogen in the surface 40 to 50 cm of mineral soil and forest floor ranged from 2,000 to 4,800 kg/ha on the four sites. On the unburned control plots, 6 to 11 percent of the nitrogen was in the forest floor. Annual burning reduced total nitrogen in the forest floor from 12 to 32 percent of the unburned treatments over the range of sites, but burning did not appear to reduce total nitrogen for the mineral soil on the burn plots over time; however, a balance sheet for the studies requires nitrogen data for the vegetation which may be causing an increase in nitrogen. While winter burning appears to increase total nitrogen in the mineral soil, summer burning appears to have a slightly deleterious effect. This observation needs to be expanded by sampling a number of sites.

Available phosphorus in mineral soil consistently increased with prescribed burning, which suggests that this may be one of the most beneficial effects of the treatment. No consistent pattern was found for burning effects on phosphorus fractions. The nature of compounds formed apparently represents specific pH conditions and mineral components in the soil. However, in all cases the burning obviously accelerated mineralization.

Except for the Louisiana study, the cation responses were quite similar. Potassium showed little effect from burning and appears to cycle in a soil mass larger than the 10-16 cm depth used for comparison. The soil depth used appeared to represent complete cycling of calcium. Trends indicated that the forest floor immobilized a large portion of the ion and in some cases altered the nutrient balance of the soil. Magnesium and calcium responded to burning treatments similarly, but their ratios indicate that magnesium appeared to recycle faster or at least to accumulate in mineral soil in the absence of burning.

It is apparent that burning will alter soil formation and long-term productivity over time. Evidence suggests that burning may improve soil by retarding soil weathering and, probably, formation of spodic layers in the profile. Further evidence of this observation would probably require five to six rotations of pine to compare soil development with and without fire.

LITERATURE CITED

Ballard, R.; Pritchett, W. L. Phosphorus retention in Coastal Plain forest soils. II. Significance to forest fertilization. Soil Sci. Am. Proc. 38: 363-366; 1974.

Bidwell, O. W.; Hole, F. D. Man as a factor of soil formation. Soil Sci. 99: 65-72; 1965.

Bray, R. H.; Kurtz, L. T. Determination of total organic and available forms of phosphorus in soils. Soil Sci. 59: 39-45; 1945.

Buol, S. W.; Hole, F. D.; McCraken, R. J. Soil genesis and classification. Ames, IA: Iowa State Univ. Press; 1973. 360 p.

Chang, S. C.; Jackson, M. L. Fractionation of soil phosphorus. Soil Sci. 84: 133-144; 1957.

Cooper, R. W. Current use and place of prescribed burning. In: Prescribed burning symposium proceedings. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1071: 21-27.

Cronan, C. S.; Reynolds, R. C., Jr.; Lang, G. E. Forest floor leaching: contributions from mineral organic and carbonic acids in New Hampshire subalpine forests. Science 200: 309-311; 1978.

Curtis, J. E.; Reeves, H. C.; Halls, L. K. Potential mineral release in loblolly and longleaf pine litter. South. J. Appl. For. 1: 18-19; 1977.

Daughtrey, Z. W.; Gilliam, J. W.; Kamprath, E. J. Phosphorus supply characteristics of acid organic soils as measured by desorption and mineralization. Soil Sci. 115: 18-24; 1973.

Day, P. R. Particle fractionation and particle-size analysis. In: Black, C. A., ed. Methods of soil analysis. Agronomy 9: 545-567; 1965.

De Kimpe, C. R.; Martel, Y. A. Effects of vegetation on the distribution of carbon, iron and aluminum in the B horizons of Northern Appalachian Spodosols. Soil Sci. Soc. Am. J. 40: 77-80; 1976.

Herbauts, J. Direct evidence of water-soluble organic matter leaching in brown earth and slightly podzolized soil. Plant and Soils 54: 317-321; 1980.

Heyward, F. The effect of frequent fires on profile development of longleaf pine forest soils. J. For. 35: 23-27; 1937.

Heyward, F.; Barnett, R. M. Effect of frequent fires on chemical composition of forest soils in the longleaf pine region. Bull. 265. Gainesville, FL: University of Florida Agricultural Experiment Station; 1934. 39 p.

Jackson, M. L. Soil chemical analysis Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1958. 498 p.

Jorgensen, J. R.; Wells, C. G. Apparent nitrogen fixation in soil influenced by prescribed burning. Soil Sci. Soc. Am. Proc. 35: 806-810; 1971.

Jorgensen, J. R.; Wells, C. G.; Metz, L. J. Nutrient changes in decomposing loblolly pine forest floor. Soil Sci. Soc. Am. J. 44: 1307-1314; 1980.

Klemmedson, J. O.; Schultz, A. M.; Jenny, H.; Biswell, H. H. Effect of prescribed burning of forest litter on total soil nitrogen. Soil Sci. Soc. Am. Proc. 26: 200-202; 1962.

Langdon, O. G. Effects of prescribed burning on timber species in the Southeastern Coastal Plain. In: Prescribed burning symposium proceedings; Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1971: 34-44.

Lewis, C. E.; Harshbarger, T. J. Shrub and herbaceous vegetation after 20 years of prescribed burning in the South Carolina Coastal Plain. J. Range Manage. 29: 13-18; 1976.

Lyle, E. S.; Adams, F. Effect of available soil calcium on taproot elongation of loblolly pine (Pinus taeda L.) seedlings. Soil Sci. Soc. Am. Proc. 35: 800-805; 1971.

McColl, J. G. Dynamics of ion transport during moisture flow from a Douglas-fir forest floor. Soil Sci. Soc. Am. Proc. 36: 668-674; 1972.

Metz, L. J.; Lotti, T.; Klawitter, R. A. Some effects of prescribed burning on Coastal Plain forest soil. Res. Pap. SE-133. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1961. 10 p.

Murad, J. L.; Berry, C. W.; Harrison, R. E. [and others]. Prescribed burning and nematode interaction in the soil of a southern pine forest. Bull. 12. Ruston, LA: School of Forestry, Louisiana Tech Univ.; 1979. 70 p.

Nelson, D. W.; Sommers, L. E. Determination of total nitrogen in plant material. Agron. J. 65: 109-112; 1973.

Olsen, S. R.; Dean, L. A. Phosphorus. In: Black, C. A., ed. Methods of soil analysis. Agronomy 9: 1035-1049; 1965.

Pritchett, W. L. Properties and management of forest soils. New York: John Wiley & Sons; 1979. 500 p.

Raison, R. J.; McGarity, J. W. Effect of plant ash on nitrogen fertilizer transformations and ammonia volatilization. Soil Sci. Soc. Am. J. 42: 140-143; 1978.

Ralston, C. W.; Hatchell, G. E. Effects of prescribed burning on physical properties of soil. In: Prescribed burning symposium proceedings. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1971; 68-84.

Switzer, G. L.; Nelson, L. E. Nutrient accumulation and cycling in loblolly pine (Pinus taeda L.) plantation ecosystems: the first twenty years. Soil Sci. Soc. Am. Proc. 36: 143-147; 1972.

Tangren, C. D.; McMahon, C. K. Contents and effects of forest fire smoke. In: Southern forestry smoke management guidebook. Gen. Tech. Rep. SE-10. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1976: 9-22.

U.S. Department of Agriculture, Soil Conservation Service. Soil interpretation records for individual soil series. USDA Soil Conservation Service Reports published 1975-1980.

Wells, C. G. Effects of prescribed burning on soil chemical properties and nutrient availability. In: Prescribed burning symposium proceedings. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1971: 86-99.

Wells, C. G.; Campbell, R. E.; DeBano, L. F. [and others]. Effects of fire on soil. Gen. Tech. Rep. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 34 p.

Wells, C. G.; Davey, C. B. Cation-exchange characteristics of forest floor materials. Soil Sci. Soc. Am. Proc. 30: 399-402; 1966.

Wells, C. G.; Jorgensen, J. R. Nutrient cycling in loblolly pine plantations. In: Bernier, B.; Winget, C. H., eds. Forest soils and forest land management. Quebec, Canada: Les Presses de l'Université Laval; 1975: 137-158.

Yaalon, D. H.; Yaron, B. Framework for man-made soil changes: an outline of metapedogenesis. Soil Sci. 102: 272-277; 1966.

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-539-000/4005

McKee, William H., Jr.
Changes in soil fertility following prescribed burning on Coastal Plain pine sites. Res. Pap. SE-234. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1982. 23 p.

Four prescribed burning studies were sampled to determine the effect of treatments on nutrient cycling and availability. Burning did not lower the level of available nitrogen in the mineral soil and accelerated cycling and availability of phosphorus and calcium.

KEYWORDS: Forest soils, forest floor mineral cycling, soil development, _Pinus palustris_, _P. elliottii_, _P. taeda_, phosphorus fractions.

McKee, William H., Jr.
Changes in soil fertility following prescribed burning on Coastal Plain pine sites. Res. Pap. SE-234. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1982. 23 p.

Four prescribed burning studies were sampled to determine the effect of treatments on nutrient cycling and availability. Burning did not lower the level of available nitrogen in the mineral soil and accelerated cycling and availability of phosphorus and calcium.

KEYWORDS: Forest soils, forest floor mineral cycling, soil development, _Pinus palustris_, _P. elliottii_, _P. taeda_, phosphorus fractions.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.