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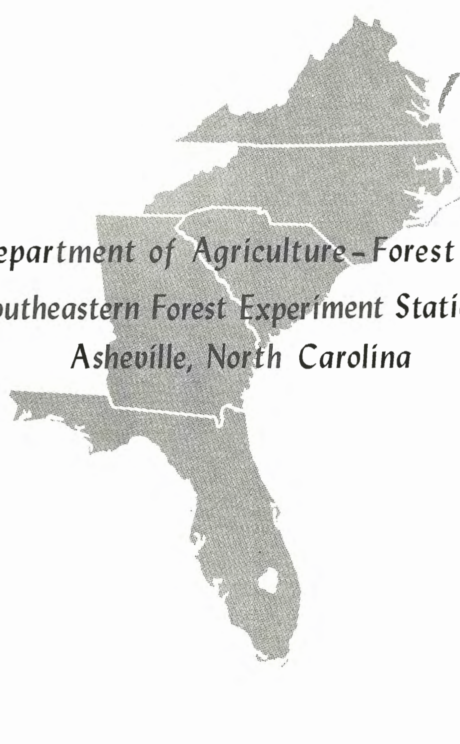

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SOME EFFECTS OF PRESCRIBED BURNING ON COASTAL PLAIN FOREST SOIL

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The usefulness of prescribed burning in the Southeast is well documented (Chaiken, 1949; Lotti and McCulley, 1951; Lotti, 1956; Wenger and Trousdell, 1957). It has been used with advantage for hazard reduction, for seedbed preparation, and for the control of broadleaved species where pine is to be the principal crop. However, the subject of prescribed burning often raises the question, "What effect does it have on the soil?" This is a pertinent question in view of the wider application of the technique with each passing year.

In an attempt to measure the effect of prescribed fire on the vegetation and soil, a study was installed in 1946 by the Southeastern Forest Experiment Station on the Santee Experimental Forest of the U. S. Forest Service, and the Westvaco Experimental Forest of the West Virginia Pulp and Paper Company. Both areas, located north of Charleston, South Carolina, are in the lower coastal plain, with loblolly pine (*Pinus taeda* L.) the predominant tree species. This report concerns the soils aspect of the study. Lotti *et al.* (1960) have already described the effects on vegetation, concluding that adequate understory control or seedbed preparation is obtainable with no serious damage to the pine growing stock.

REVIEW OF LITERATURE

Most of the work in the South on the effect of fire on soil properties has been done in the longleaf pine (*Pinus palustris* Mill.) type during the 1930's. The majority of the studies concerns wildfires rather than prescribed burning. Heyward made the most thorough investigation and reported, along with others, on several aspects of the problem.

Heyward and Barnette (1934), working in coastal plain longleaf pine stands from Virginia to Louisiana, found that the pH was higher on burned soil because of release of mineral elements in the ash. The calcium content increased 100 percent and the nitrogen 14 percent on the burned soils. All observed chemical changes ascribable to fire were restricted to the top 4 to 6 inches of soil. Concerning the physical state of the soil, the authors wrote: "The mellow, permeable surface soil on unburned areas contrasted strikingly with the compact, impermeable soil on the burned areas."

Barnette and Hester (1930), studying the effect of burning on soil in Florida, compared the soil beneath a virgin longleaf stand with soil on an area that had been burned almost annually for 42 years. They state that the organic matter and nitrogen content were greater on the unburned site. It should be noted that the areas studied were about 80 miles apart and that all timber had been cut from the burned area about 3 years before the measurements were made.

In contrast, Greene (1935), while working in the longleaf pine region of Mississippi, found that burned soils contained 1½ times as much nitrogen as soils protected from fire, and that burning increased the organic matter content 1.6 times in the surface 6 inches of soil. These increases are attributed to the decay of plant roots; the annual use of fire approximately doubled the growth of grasses and legumes.

Studying the soil fauna of burned areas, Heyward and Tissot (1936) noted that although the same microfaunal groups were found in both burned and unburned soils, the top 2 inches of the unburned mineral soil contained eleven times more animals than the corresponding depth on the burned areas. They state, "The diversified active soil fauna of the unburned areas is believed responsible for the penetrable and well aerated soil typical of such areas. This is in striking contrast to the more compact, less porous soil of frequently burned areas in which animal activities are much less abundant."

Investigating the soil temperatures during fires, Heyward (1938) states, "An important point brought out by the present study is the fact that, at a soil depth of only ⅛- to ¼-inch, the heat generated by hot forest fires in the longleaf pine region is insufficient to destroy organic matter. Since the maximum temperature recorded was approximately 275°F., it is clear that organic matter was neither charred (and thereby made resistant to decomposition) nor destroyed by heat generated by these fires."

Burns (1952), in studying the effect of fire on level sandy soils in New Jersey, concludes that: "1. Moderate burning treatments benefit the mineral soil chemically and probably have favorable effects on the forest floor. 2. Annual burning for long periods has unfavorable effects on the forest floor but benefits the mineral soil chemically. 3. Controlled burning is of little or no importance from the standpoint of the physical properties of the mineral soil."

Very comprehensive literature reviews and lists of references are found in the works of Shantz (1947) and Burns (1952).

Results of studies concerned with the effect of fire on soil have often been contradictory. Some of the contradiction undoubtedly comes from variation in study design, sampling techniques, and analytical procedures. However, some of the differences are from variation in sites which have been studied. It should not be expected that all conclusions drawn from studies of mountainous soils can be applied to coastal plain areas, or that results from a site with a thick mor humus type are applicable to an area with a mull humus type.

A universal answer to fire effects has not been, and probably will not be, found because of the variations in the soils, climate, and vegetation of the forested regions of the country.

METHODS

Area

The experimental areas for this study were in previously unmanaged but well-stocked, even-aged, loblolly pine stands that contained uniformly distributed, heavy understories (fig. 1). In each case the loblolly pine overstories also had some scattered shortleaf pine (*Pinus echinata* Mill.), an occasional longleaf pine, and miscellaneous hardwoods. The Santee plots, installed in a 40-year-old stand, had 3 light intermediate cuts, one at the beginning of the study followed by 2 cuts at 5-year intervals. The 30-year-old stand on the Westvaco forest was cut twice, at the beginning of the experiment and 10 years later.

Figure 1.—Stand conditions at the Santee Experimental Forest location in 1947 before any prescribed burning. Small understory stems are mainly sweetgum and southern bayberry.

All were commercial operations, in which the stands were thinned mainly from below, with very little disturbance of the overwood or understory. The understories consisted of many hardwood tree species. Approximate stocking by species groups was 60 percent gum (*Liquidambar styraciflua* L.) and (*Nyssa sylvatica* Marsh.), 30 percent mixed oaks (*Quercus* spp.), and 10 percent other species. Many shrubs were also present, including pepperbush (*Clethra tomentosa* Lam.), and gallberry (*Ilex glabra* L., A. Gray). Much of the understory at each location was about 15 years old, and dated from the last wildfire.

Both experimental forests lie within the flatwoods portion of the coastal plain at elevations of about 40 feet above sea level. The burning experiment was installed on Coxville very fine sandy loam, a poorly drained soil with very slow surface runoff and medium to very slow permeability. The soil occurs on level to slightly undulating terrain and is found over much of the lower coastal plain of South Carolina, both in the higher and lower flatwoods areas. Characteristically, the soil has a surface layer of 2 or 3 inches of dark grey, very friable, fine sandy loam which blends into a light grey, very friable, fine sandy loam with some yellowish mottlings appearing at a depth of about one foot. From 12 to 20 inches there is a mottled light grey, yellow to reddish-yellow, slightly plastic, fine sandy clay loam which overlays a clay containing mottlings of red, yellow, and grey.

The whole profile is very acid, low in nutrients, and the organic matter content decreases sharply below the surface 3 or 4 inches.

Surface runoff is fairly slow because of nearly level topography; during wet seasons water stands in depressions for several days following rains.

The soils on the two areas differ in depth to the clay layer; on the Santee the clay layer is about 12 inches below the surface, and on the Westvaco it is about 4 inches below the surface. This probably accounts for the difference in site index between the two areas: 95 on the Santee and 90 on the Westvaco land.

Plots and Data Collection

The study is based on prescribed burning tests carried out on ¼-acre plots located in the two previously described loblolly pine stands. Three replications of all treatments are at the Santee Forest location and two at Westvaco. Thus there were five plots for each of the following five treatments: annual winter fire, annual summer fire, periodic winter fire, periodic summer fire, and control (no fire). Soils were studied on all 25 plots.

On the annual fire plots there were ten consecutive fires from the time the study began until the soil data were collected. The periodic plots received two fires during this period. All of the winter and summer periodic plots were burned in 1947; however, the winter plots were reburned in 1951 and the summer plots in 1954.

On each plot, 15 random samples were collected in the surface 4 inches of soil. An undisturbed core (2 inches deep, 3 inches in diameter) was taken from the 0-to 2-inch and 2- to 4-inch depths. Immediately next to each core, a small bag of loose soil was collected for organic matter and nutrient analyses. Analytical work was directed by the Union Soils Laboratory of the Southeastern Forest Experiment Station.

Core samples were analyzed in the laboratory according to procedures given by Hoover *et al.* (1954). Determinations included bulk density, percentage by volume of detention and retention pores, and percolation rates.

Loose soil samples were passed through a 0.5 mm. sieve and organic matter was determined by the loss-on-ignition (450° C. for 4 hours) and a modification of the Walkley-Black wet combustion method (Jackson, 1958). Loss-on-ignition measures elementary carbon (*e.g.,* charcoal) while the wet combustion method excludes 90 to 95 percent of it. Other chemical analyses on composites of the loose samples included nitrogen, phosphorus, potassium, calcium, magnesium, and soil reaction.

In addition, four to eight samples from each of the surface organic layers were collected from the Santee plots only. On the control plots the humus type was a duff mull. These samples were 1 square foot in size and included all organic material down to mineral soil. They were ovendried and then burned in a muffle furnace to eliminate the weight of mineral matter inadvertently picked up during the sampling. Therefore, the reported forest floor weights are expressed in pounds per acre on a volatile matter basis, rather than on an ovendry basis.

RESULTS

Physical Properties

The physical properties of pore space, percolation, and bulk density are important from the standpoint of erosion and the growth of vegetation. Growth is dependent on aeration and water movement in the soil (porosity and percolation rates are estimates of these) and in general is better on soils with low bulk density, high detention storage space, and high percolation rates.

Bulk density, a measure of the solid particles per unit volume, gives estimates of porosity and relative compactness of the soil. In general the bulk density of mineral soils ranges from less than 1.0 for porous soils to around 1.5 for compact ones.

The total porosity, or volume of air in the soil, can be separated into two parts. The large pores are those which detain water for only a day or so and their volume is called detention pore space. The small pores are those which retain water for considerable periods of time against the force of gravity and their volume is called retention pore space. The sum of the detention and retention pores is equal to the total porosity.

The percolation rate, a measure of the movement of water through soil, is expressed as inches per hour. Since the sample collected is but a segment of the profile of the soil, and is subjected to unnatural wetting conditions in the laboratory, these rates are only relative.

As is true of most soils, the bulk density in the surface 2 inches on the study plots is considerably lower than that of the 2 to 4 inch depth, showing that the surface soil is looser and more porous than that beneath (table 1). Detention or large pore space is also greater in the surface 2 inches. There is a close relationship between the percent by volume of detention pore space and percolation rate ($r=.80$).

Statistical analysis of the data showed no significant differences between treatments for any of the physical soil properties measured for either depth. Although some of the tabular values differ considerably, the within-plot variation prevented the differences from being significant. It appears that the various burning treatments, in comparison with the control, have neither benefited nor adversely affected the physical soil properties measured.

Table 1.—Some physical properties in the upper four inches of the soil related to fire treatments

Treatment	Bulk density	Retention pore space	Detention pore space	Percolation rate
	Grams per cubic centimeter	*Percent by volume*	*Percent by volume*	*Inches per hour*
0- TO 2-INCH DEPTH				
Annual winter	0.98	36.60	20.57	8.52
Annual summer	1.01	38.53	17.13	5.13
Periodic winter	1.10	35.89	17.91	4.83
Periodic summer	1.02	35.99	21.50	8.96
None (Check)	1.04	36.08	19.58	8.10
2- TO 4-INCH DEPTH				
Annual winter	1.24	34.42	14.59	2.57
Annual summer	1.29	35.12	11.88	1.80
Periodic winter	1.35	32.09	12.70	1.84
Periodic summer	1.34	32.26	13.99	2.80
None (Check)	1.29	33.96	13.22	1.70

Organic Matter

Organic matter values for the surface 2 inches of the soil under the various treatments showed significant differences at the 1 percent level between the annual summer and the periodic winter fires, and between the annual winter and periodic winter fires (table 2). Differences, significant at the 5 percent level, were noted for both the annual summer and annual winter when compared with the control, and between the periodic summer and the periodic winter fires.

Thus, organic matter in the mineral soil increased with all treatments except the periodic winter fire. When results were first obtained as loss-on-ignition values, it was suspected that much of the organic matter measured was charcoal. A subsequent analysis of the same samples by the wet combustion method showed the ranking of the various treatments in the same order, although the organic matter was several percent less on all plots.

The organic matter incorporated in the surface 2 inches of mineral soil (measured by the wet combustion method), and that resting on the soil surface, is given on a weight per acre basis in table 3. Percentage by weight in the mineral soil was converted to pounds by using bulk density, or weight of the soil. Since bulk density did not differ significantly between the treatments, the average for all plots was used. Therefore, the ranking of treatments with respect to soil organic matter is the same whether results are expressed on a percentage or weight basis.

Table 2.—Organic matter content in surface two inches of the forest soil in relation to prescribed burning treatment

Treatment	Organic matter based on ovendry weight	
	Wet combustion	Loss on ignition
	Percent	*Percent*
Annual winter fire	10.76	15.38
Annual summer fire	10.80	16.00
Periodic winter fire	7.04	8.14
Periodic summer fire	9.49	10.16
No fire (Check)	7.79	9.71

Table 3.—Weight of organic matter in pounds per acre for the surface two inches of mineral soil and the litter layer by various prescribed burning treatments

Treatment	Time since last burned	Organic matter		
		In mineral soil	On surface	Total
	Years	- - - - *Pounds* - - - -		
Annual winter fire	0.75	50,210	4,990	55,200
Annual summer fire	.25	50,390	3,860	54,250
Periodic winter fire	4.75	32,850	16,670	49,520
Periodic summer fire	2.25	44,280	9,520	53,800
No fire (Control)	25+	36,350	16,580	52,930

Apparently the maximum forest floor weight under the stand conditions studied is about 17,000 pounds per acre, as found on the control plots (fig. 2). The presence of an equivalent amount of surface organic matter on the periodic winter burn plots, however, is considered not so much the result of the accumulation since the last fire (4.75 years) as it is the small amount of fuel consumed by each fire. This is borne out by a supplemental measurement made on one plot after a periodic winter fire that showed only 4,000 pounds of organic matter per acre consumed by the single fire. In contrast, the periodic summer burns appear to be somewhat more intense, a fact reflected by the tabular values that show less than 10,000 pounds of surface material per acre even after 4 years. Some unburned organic matter remains on the surface even after 10 annual fires (winter or summer), as evidenced by the 4,000 to 5,000 pounds per acre measured shortly after the last burn but before the autumn fall of needles, twigs, bark, etc. (fig. 3).

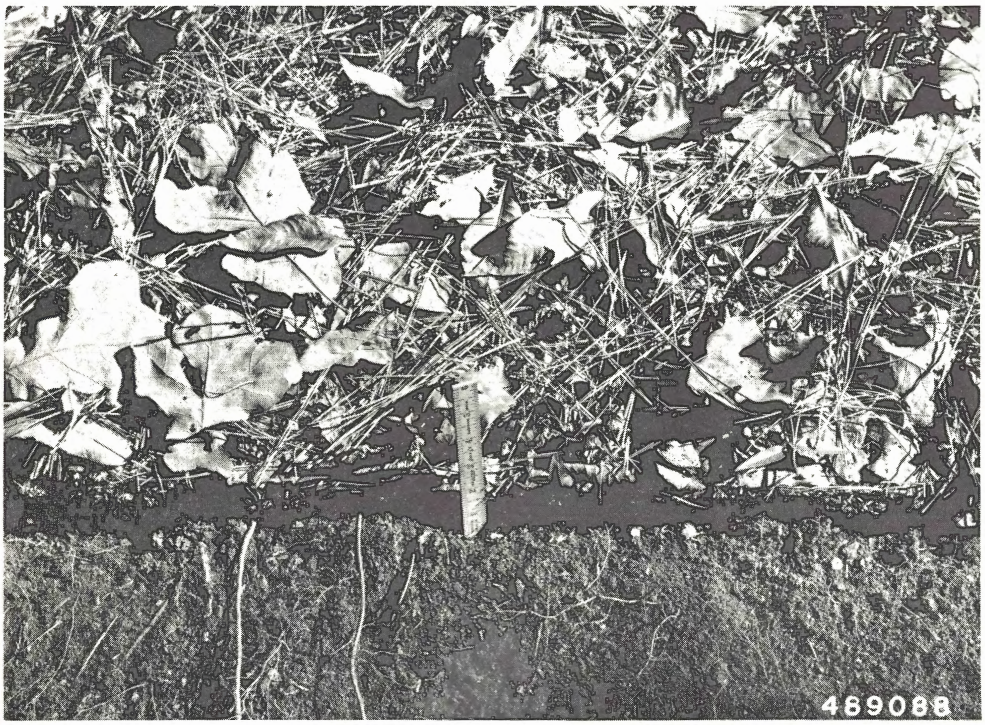

Figure 2.—Surface organic matter on unburned plot. In foreground the organic matter has been removed to show depth to mineral soil.

Figure 3.—Bird's eye view of forest floor on annual summer burn plot. Frame is 2 feet square and encloses area showing residual surface organic matter left after last burn. Area outside frame shows about one year's accumulation following last burn.

All plots have about the same total amount of organic matter present, but the vertical location of the material differs. Assuming the forest floor is not washed away, it is lost from the site by oxidation. The rate of oxidation depends on the treatment applied to the forest, whether it be burning, clear cutting, or some other silvicultural practice.

In an undisturbed forest floor the material slowly disintegrates and decomposes. Some of it moves into the mineral soil; some of it goes into the atmosphere as carbon dioxide and water. The material moving into the mineral soil becomes soil organic matter and a slow rate of decomposition continues until the material disappears. When a forest floor is burned there is a rapid decomposition and much of the material moves quickly into the atmosphere. The fine residue moves down into the mineral soil. This charred matter is also slow to decompose and with continued fires it tends to build up in the surface layers of the mineral soil.

Chemical Properties

A composite was taken from the 15 samples of loose soil on each plot and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, and acidity. Total nitrogen was determined by the Kjeldahl method; available phosphorus was extracted with Bray No. 2 extractant using 5 grams of soil and 50 ml. of solution, shaking for 5 minutes, and analyzing colorimetrically; potassium, calcium, and magnesium were measured as exchangeable cations on a flame photometer after being extracted in 1 N ammonium acetate; and pH was measured on a soil paste with a glass electrode. These standard procedures are described by Jackson (1958).

The results of this work, shown in table 4, are related quite closely with the organic matter content of the different treatments. In general, the greatest amount of nutrients was found on the annual summer and annual winter burns, and the minimum quantity on the periodic winter fire.

Table 4.—Amount of nutrients and pH in surface four inches of soil as affected by prescribed burning treatment

0- TO 2-INCH DEPTH

Treatment	Nutrients					
	N	P[1]	K	Ca	Mg	pH
	- - - *Parts per million* - - -					
Annual winter fire	1664	24	56	282	86	4.4
Annual summer fire	2038	26	54	435	96	4.8
Periodic winter fire	1129	14	29	168	48	4.2
Periodic summer fire	1478	19	36	252	52	4.3
No fire (Control)	1238	13	36	174	52	4.2
2- TO 4-INCH DEPTH						
Annual winter fire	862	13	30	86	42	4.6
Annual summer fire	834	8	24	94	39	4.7
Periodic winter fire	577	9	19	68	20	4.5
Periodic summer fire	712	9	21	96	24	4.6
No fire (Control)	702	7	24	85	34	4.5

[1] The Truog method as used on agricultural soils yielded but 3 to 7 ppm of phosphorus (no significance between treatments).

This same trend holds for both the 0- to 2-inch and 2- to 4-inch layers. Significant differences develop between treatments for the magnesium content in the 0- to 2-inch soil layer; amounts on the annual summer fire plots are greater than those on either of the periodic treatments or the control (1 percent level). For available phosphorus content in the 0- to 2-inch depth both annual treatments contained significantly more than in the control and periodic winter treatments, and the annual summer fire was greater than the periodic summer fire (5 percent level). None of the other treatment differences given in the table are significant at the 5 or 1 percent levels.

DISCUSSION

Since the physical properties of the soil studied are measures of compactness and water movement in the mineral soil, any changes should indicate whether the soil has been improved or depleted as a result of prescribed burning. It should be realized, however, that the sites studied have all had many burns in the past (charcoal was evident in A_1 horizon of control plots) and that the period of experimentation covers but an infinitesimal part of the life of the soil.

The type and frequency of fires used had no detrimental effect on bulk density, porosity, or percolation rate of the soil. All of these factors are somewhat dependent on the organic matter in the soil because the organic material tends to "fluff-up" the mineral soil. The data in tables 1 and 2 indicate the relationship between the bulk density and organic matter content of the surface two inches of mineral soil. The two types of annual fire plots have the lowest bulk density and also the highest organic matter content, whereas the control and periodic winter burning plots have the highest bulk density and the lowest organic matter content.

An increase in organic matter following fire, when measured as loss-on-ignition, has been noted by Heyward and Barnette (1934) in their studies of soil beneath longleaf pine. Shantz (1947) claims that this and other studies are deceptive because "loss-on-ignition, never reliable as a method in determining the organic matter in soils, is especially misleading when applied to the southern soils." It is true that loss-on-ignition values are only estimates of organic matter, and if charcoal is present in the soil the estimates are less reliable. Nevertheless, there was good correlation between the ignition and wet-combustion methods used in this study. Ignition values were always higher than the wet-combustion values, the difference varying from 5.20 percent for the annual summer fires to 0.67 percent for the periodic summer fire (table 2).

The organic matter beneath the burned sites is very black and gives the appearance of fine bits of charcoal. Analysis by the wet-combustion method, however, which measures only 5 to 10 percent of the charcoal, still shows an increase in organic matter over the unburned areas. Much of the burned forest floor is not converted to ash, and the material which appears to be charcoal is actually charred material which tends to decompose slowly.

Heyward (1938) found that the maximum temperature in the surface ¼ inch of mineral soil was 275° F. Although temperatures were not measured in the present study there is no reason to assume they would be higher. Except for the initial burn that all plots except the control received, the amount of forest floor, or fuel, was probably no greater than Heyward encountered. Small test burns have shown that undecomposed organic matter buried ¼ inch below the soil surface is not charred even under a heavy forest floor. Therefore, the high organic matter content of the burned soil is not from material charred in place, but is material charred on the surface and translocated into the mineral soil, primarily by water.

Some workers have reported the increase in organic matter in the mineral soil following burning was caused by stimulation of grasses. On the annual burns in this study, however, the annual vegetation was sparse (fig. 4).

The chemical analyses show that although the fertility level is low on all plots, the burning treatments have made additions of nutrients to the surface mineral soil in the past ten years. This is to be expected with the mineral elements where the topography is level and there is little or no erosion. Elements ordinarily bound up in the surface layers of organic material are released by fire.

It has often been stated that burning of the forest floor releases all of the nitrogen in the material. This may be true where fire converts the organic material into a white ash, but the charred material left on the soil surface after a fire does contain nitrogen. Tryon (1948) reports hardwood charcoal contains 0.21 percent total nitrogen and conifer charcoal 0.01 percent. Samples

Figure 4.—View of annual summer fire plot almost one year after 10th burn. Note absence of any understory vegetation.

of burned forest floor collected on the Santee Experimental Forest show appreciable nitrogen present. Litter from an unburned patch composed of recently fallen fuels contained 0.46 percent total nitrogen, and burned litter contained from 0.42 percent to 0.76 percent total nitrogen. All of these values are on an ovendry weight basis and an increase in the percentage of nitrogen in the burned material is a reflection of the concentration of nitrogen in the charred residue.

More than likely, the results of this study cannot be applied to sloping terrain or to sites on which the soil at the surface is not sandy. On the sites studied there is practically no horizontal movement of surface water. On sloping land, water moving over the surface would tend to carry ash and charred material from the site and at the same time material in suspension would settle out and plug the surface soil pores. Sealing of the surface by material carried in moving water would be more rapid on non-sandy soils. And of course, in the Piedmont, mountains, and sandhills, where soils, vegetation, and topography differ greatly from the coastal plain, prescribed burning might be detrimental to the site.

SUMMARY

A study was made from 1946 to 1956 of the effect of prescribed burning on soils beneath loblolly pine stands growing in the level, lower coastal plain of the Southeastern United States. Data were collected on two experimental areas located about 30 miles apart in South Carolina. The sites are comparable in that they have similar topography and surface soil texture. Annual and periodic fires over a ten-year period had no significant influence on the physical properties of the soil. Mineral elements, nitrogen, and organic matter tended to increase in the surface 4 inches of the burned plots.

Conclusions drawn from this experiment can probably be applied to the flat, low-lying, sandy surface soils of the region.

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