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Some Effects of Prescribed Burning on the Soil,
Forest Floor, and Vegetation in the Loblolly-
Shortleaf Pine Forest of the Upper Coastal Plain
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SOME EARLY EFFECTS OF PRESCRIBED BURNING ON THE SOIL,
FOREST FLOOR, AND VEGETATION IN THE LOBLOLLY-
SHORTLEAF PINE FOREST OF THE UPPER
COASTAL PLAIN OF ALABAMA

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ABSTRACT

The study involved the testing of two burning treatments and a hardwood poisoning treatment for effects on soil, forest floor, and vegetation properties in the Upper Coastal Plain region of Alabama. The work was done at the Fayette Experiment Forest, a branch of the Alabama Polytechnic Institute located about 60 miles west of the city of Birmingham. The topography is strongly hilly. The soils are typical upland red and yellow podzolic soils with sandy loam or loamy sand topsoils and sandy clay loam to heavy clay subsoils. The experimental plots were located on old-field areas, many of which had suffered moderate to severe sheet and gully erosion under past cultivation. The vegetative cover consisted of open to dense stands of loblolly pine (Pinus taeda L.) and shortleaf pine (Pinus echinata Mill.) with variable amounts of hardwood, shrub, vine, grass, and forb species being present as subordinate vegetation.

The burning treatments consisted of August burning, applied in 1951 and in 1954, and January burning, applied in 1952 and in 1955, with suitable check plots being protected from fire. The hardwood poisoning treatment, applied in the spring of 1952, was superimposed on the burning treatments by splitting each main plot into a poisoned and a nonpoisoned subplot; the treatment consisted of killing with ammonium sulfamate an average of 6.23 square feet of basal area per acre in hardwoods over 3 inches in diameter breast high. All treatments were applied on ridges and on slopes. There were 6 replications,

36 main plots, and 72 subplots. Measurements were made and samples were taken in the winter and spring of 1953-54 previous to the second burnings, and again in the late winter and spring of 1955 subsequent to the second burnings.

Burnings were applied on clear days within a few days after substantial rains. The 1951-52 burnings, having 10 years of fuel accumulation, were hotter and caused greater changes than the 1954-55 repeat burnings. The August burnings reduced the forest floor more than the January burnings, and the second August burnings left a dangerously thin residual floor on some plots; however, normal autumn leaf fall apparently soon gave adequate protection against damage to the mineral topsoil from raindrop impact. Generally the loss of nitrogen, potassium, calcium, and phosphorous from the forest floor was in direct proportion to loss of the forest floor itself.

Burning raised the pH of the top 3 inches of mineral soil and added more potassium and calcium to it than the forest floor had lost. The gains were presumed to have come from live vegetation killed by the fires. Available phosphate was increased, but only the repeat burnings appeared to have contributed the additions. Because the soils were extremely low in available phosphate, it was deduced that roots had absorbed additions made available by the 1951-52 burnings during the interval between the burnings and the measurements in 1953-54. Burning caused no change in total soil nitrogen or in soil organic matter.

Burning produced no effects on total porosity, macro-porosity, and micro-porosity of the top 3 inches of mineral soil. There were no significant differences in infiltration rates which were measured only once, in 1955. This may have been due however to the impossibility of statistically removing the strong effects on this factor of past erosion.

Legumes, composites, and euphorbs increased in density of cover in the first growing season after burning, but probably went back to normal thereafter. By the middle of the third growing season, shrubs and vines increased, with January burning showing more increase than August burning. Hardwood cover 6 feet high and under was reduced by burning but was back to normal in the third growing season. Only August burning significantly reduced the cover of all vegetation more than 6 feet high. Grass cover may have been reduced the first season after burning, but subsequently it varied inversely with the total cover of trees, shrubs, and vines.

The only effect of hardwood poisoning seemed to be an increase of soil nitrogen and organic matter on ridges.

It was concluded tentatively that prescribed burning can be applied in the Upper Coastal Plain region of Alabama without significant harm to the soil. More refined experiments are needed to determine which vegetational types at what minimum densities can be burned frequently enough for effective hardwood control without exposing the topsoil to physical deterioration. Nitrogen and organic matter levels of the mineral soil must be checked in the future to verify the assumption that herbaceous vegetation stimulated by burning will replace losses from the forest floor.

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INTRODUCTION

Certain destructive effects of severe, uncontrolled forest fires are generally well known by foresters and laymen alike. Among these, floods and erosion are usually thought of as the results of damage to the forest soil. Foresters learn from their standard texts that these effects arise largely from a deterioration of the physical properties of the soil following fire, and learn further that nearly all forest fires, regardless of severity, in the long run cause some physical or chemical deterioration in the soil (Lutz and Chandler, 1946; Wilde, 1946; Baker 1934, 1950). In one text (Toumey and Korstian, 1947) they find mention of possible beneficial chemical effects on the soil of controlled fire, but the same text strongly emphasizes the work of Shaw and Kotok (1924) in ascribing heavy damages in general "even to light surface fires when these are repeated at intervals".

Nevertheless, it is known that certain of the more valuable forest types originated as a result of forest fires or other land clearing agencies and have been perpetuated only because of periodic fires. Prominent examples in this category are the Pacific Douglas-fir type, the western white pine type, and the longleaf pine type. Pure pine stands of loblolly and shortleaf pines generally owe their existence to agricultural clearing and abandonment, but loblolly-hardwood and loblolly-shortleaf-hardwood mixtures have been described as fire sub-climaxes (Chapman, 1942; Garren, 1943). In either case, succession

toward pure hardwoods is rapid and strong under complete fire protection (Barrett and Downs, 1943; Chaiken, 1949; Coile, 1950; Oosting, 1942; Wahlenberg, 1949; Wells, 1928). For all these types, the suggestion is implicit that fire might be an effective and economical tool in maintaining a good representation of the more valuable species. It is not necessarily believed that all detrimental effects to the soil can be avoided, but rather it is hoped that these effects will be slight and non-accumulative, and that the over-all benefits to be obtained will exceed the losses suffered.

Pursuant to the above, fire has been successfully used as a silvicultural tool in widely separated regions of the United States. Kallander et al. (1955) showed that important fire hazard reduction was obtained at comparatively little cost as the result of a prescribed fire in the ponderosa pine type of Arizona. Periodic reduction of fuel accumulations can be as important to the preservation of a valuable forest type as can the periodic reduction of inferior tree species. Biswell et al. (1955) described the successful use of prescribed winter and early spring burning to reduce fire hazard and to improve the game habitat in the ponderosa pine type of the north Coast Range and of the Central Sierra Nevada Mountains in California--this in spite of the dire predictions made by Shaw and Kotok (1924) as to the results to be expected from any use of controlled burning in the California pine forests. Even the Lake States region has its advocate of prescribed burning in Spurr (1954) who stated that the red pine-jack pine forests of Itasca in Minnesota are fire climax and can be preserved only by means of early burning or chemical control of hardwoods. Little

et al. (1948) and Little and Moore (1953) have tested and approved prescribed burning methods for controlling hardwoods and for reducing fire hazard on shortleaf pine and pitch pine sites of the New Jersey coastal plain. Little and Mohr (1954) estimated that loblolly and pond pines might make up 80 per cent of the future stand where they had applied summer burning after logging on the eastern shore of Maryland, while in unburned areas pine would dominate only in spots that had been greatly disturbed in logging.

In the Southeast, the development of fire as a silvicultural tool in the longleaf pine type of the Lower and Middle Coastal Plain regions has claimed national attention. Here prescribed burning is not only considered necessary for fire hazard reduction and competition control, but is also considered as essential for seedbed preparation and as virtually indispensable for disease control (Wahlenberg, 1946). McCulley (1950) gave directions for the prescribed burning of slash pine stands in the Lower Coastal Plain region (flatwoods) of south Georgia and north Florida in order to reduce fire hazard and to control competition. Prescribed burning has been so well accepted for longleaf pine and slash pine types that directions for its use were included in a widely distributed extension bulletin (Dyer and Brightwell, 1955). Wildlife managers consider prescribed burning as essential in these types for maintaining good food and cover conditions for bobwhite quail and wild turkey (Stoddard, 1935).

In the loblolly pine types of the Southeast, prescribed burning has gained acceptance in two widely separated areas, these being (1) the Gulf coastal plain region west of the Mississippi River and (2)

the coastal plain of the south Atlantic states. In both areas, burning has been used primarily for hardwood control with fire hazard reduction and seedbed preparation as important secondary objectives. For loblolly pine-hardwood stands west of the Mississippi in Arkansas and Louisiana, Chapman (1942) advocated summer burning after harvesting the mature crop and winter burning at 10-year intervals between harvests. Silker (1955) gave detailed directions for prescribed burning as the result of tests in loblolly stands, loblolly-hardwood stands, and slash pine plantations in the flatwoods of Texas. Harrington and Stephenson (1955) described the effectiveness of repeated spring burns in reducing the number of small hardwoods per acre in Texas. For the south Atlantic region, Riebold (1955) gave a detailed program of prescribed burning used in the loblolly type in the Francis Marion National Forest on the lower coastal plain of South Carolina. Lotti (1956a) described the relative effectiveness of winter and summer burns in killing hardwoods in loblolly stands of the South Carolina flatwoods, and recommended, for the purposes of hardwood control and seedbed preparation, a series of annual summer fires previous to the harvest, and periodic winter fires for interim hardwood control. A recent U. S. Forest Service publication, designed for the use of forest landowners on the South Atlantic coastal plain, discussed the use of prescribed burning in the loblolly pine type and advised owners to seek technical help whenever they felt that burning might be advisable (Lotti, 1956b).

Thus it can be seen that in the Southeast prescribed burning has come to be accepted as a silvicultural tool useful in the management

of pine stands growing in regions of flat to gently rolling topography and generally of sandy topsoils. Soil studies, to be discussed in detail in the next section, have shown that prescribed fires can be used effectively in these areas with no more than negligible damage to the soil. No such studies have been reported, however, for the Piedmont region or for the vast Upper Coastal Plain region of Georgia, Alabama, and Mississippi. Loblolly and shortleaf pines, dominant in these regions along with various hardwood species, hold precisely the same successional position there as does loblolly pine west of the Mississippi River and loblolly pine on the coastal plain of the south Atlantic states. As outlined by Bruce (1955), however, other conditions tend to be different. Because the land tends to be more sloping and the soils heavier and more easily compacted, erosion occurs more readily and backfires are harder to control. The fuels are different and often difficult to burn uniformly. As stated by Folweiler (1952), there is still much to be learned just within the coastal plain formation. Only Chapman (1947) has made prescribed burning recommendations that can be said to be intended for the Upper Coastal Plain and for the Piedmont (as well as for other regions); other foresters await experimental data which will guide them in designing prescribed burns that will be effective and at the same time compatible with local conditions.

More than a third of Alabama's area is in the upper coastal plain formation. Topography is gently rolling to almost mountainous. Soils are divided into upland and lowland types, but the upland types predominate. On the upland soils, the hardwood species that tend so

strongly to displace the pines are almost always more or less inferior to the pines in growth rate and in quality. Wheeler (1953) gave quantitative information on hardwood gains and softwood losses for an eight-county sector of the Upper Coastal Plain region that includes the experimental area used for the study reported herein. He referred to this sector as the west central region of the state, and gave the following changes as having occurred from 1935-36 to 1951-53:

Areas

All forest types	+ 15%
Pine and pine-hardwood	+ 7%
Upland hardwood	+ 52%
Lowland hardwood	+ 14%

Growing stock

All species	negligible change
Pines	- 14%
Hardwoods	+ 12%

The new area in "all forest types" was predominantly old field pine area. The addition of 15 per cent to the total forest area from this source should have added perhaps 30 per cent to the pine and pine-hardwood area. The difference between this figure and the 7 per cent actually gained represents loss to the hardwood types over the 16-year period, a loss of more than 1 per cent per year.

An obvious approach to the hardwood succession problem in the Upper Coastal Plain region is to try various promising prescribed burning techniques under different conditions of soil, topography, and fuel, and then to measure silvicultural effectiveness and soil

changes in each case. The present paper reports on soil changes resulting from a study of this type in the Upper Coastal Plain region of Alabama. It also reports on certain changes in the forest floor and in lesser vegetation brought on by the burnings. It reports further on changes in soil, forest floor, and minor vegetation resulting from hardwood poisoning treatments which accompanied the burning treatments, but these changes are predictably negligible because of the lightness of the treatments given and because of the shortness of the time elapsed since the treatments.

In instituting the soil phases of this study, various authorities were consulted as to the kind of soils information needed (Dorman and Metz, 1952; Grosenbaugh, 1953; Korstian, 1953; Ostrom, 1953; Stone, 1953). The consensus seemed to be that physical soil changes should be emphasized, but that chemical changes should not be ignored. All authorities emphasized the importance of detecting soil changes connected with prescribed burning, but Stone (1953) warned that conclusive results in terms of site deterioration would be long in developing. He stated that first studies should be exploratory in nature, aimed at indicating the magnitude of the variables involved. This study has been designed with all of these principles in mind.

REVIEW OF LITERATURE

Basic Considerations

Combustion during forest fires can occur only in the organic portion of forest soils. Most obviously, it occurs on the forest floor¹, which is partially or entirely "consumed" by flames. Organic matter within the mineral soil, even that within the top inch of the A₁ horizon, is burned only under heavy surface fuels during the course of very hot wild fires or slash fires. Heiberg (1942) was unable to maintain combustion in mulls with organic matter contents up to 60 per cent unless he used an outside source of heat. Heyward (1938) found that a temperature of 350° F. was necessary to cause charring of dry organic matter; during experimental burning, he was unable to obtain, at less than 1/4 inch into the mineral soil, a temperature of more than 275° F. even under piled pine straw. Beadle (1940) obtained a maximum of 153° F. at one inch in sandy soil in New South Wales. Hoffman (1924) reported only 60° F. in the mineral soil under a slash fire in Douglas-fir, western hemlock, and western redcedar that developed 850° F. 30 inches above the ground; the fire, however, did not consume the lower 1.5 inches of duff. Fowells and Stephenson (1934), on the other hand, found that slash burning after clearcutting Douglas-fir may destroy some of the organic matter in the immediate mineral

¹The term "forest floor" is used in this paper to indicate all unincorporated organic matter at the top of the soil profile, or the A₀ and A₀₀ horizons.

soil surface, and Isaac and Hopkins (1937) recorded a temperature of 608° F. at one inch below the surface under a burning slash pile in a clearcut Douglas-fir area.

In order to appraise the possible effects of fires on forest soils, one should review then the role of organic matter in forest soils. Organic matter is the source of good soil structure in forest soils. Lassen et al. (1952) stated that if a minimum clay content of 8 to 10 per cent is present, organic matter will cause an increase in non-capillary pore space through the formation of aggregates. Since organic matter affects structure of the soil, it also affects its aeration. It greatly increases the moisture equivalent of sandy soils and increases the wilting percentage to a lesser degree (Coile, 1938). In heavier soils, organic matter increases moisture equivalent to a lesser extent than in sandy soils and has a negligible effect on the wilting percentage. Organic matter also increases total porosity, depth of the topsoil, and total water storage capacity (Lassen et al., 1952). It is a storehouse of nutrients necessary to plant growth, and in the form of humus, has a high cation exchange capacity. Recently interest has been focused on the role of organic matter in holding the minor nutrient elements in complex organic molecules where they are readily available to plants but not readily lost or made unavailable (Peterson, 1956). It is significant that most tree roots are found in or near soil horizons that are relatively high in organic matter.

The forest floor serves as a reserve source of humus and plant nutrients for the soil. However, if the forest floor is completely removed, roles of more urgent importance immediately become evident.

Due to exposure to raindrop impact, the mineral soil surface tends to lose its infiltration capacity because the macro-pores at the surface become clogged or sealed with fine soil particles filtered from the percolating water (Lowdermilk, 1930). The effect is, of course, more serious on heavier textured soils. It is illustrated by Kittredge's (1938) finding of an average infiltration rate for a forest soil that was four times the rate for an open soil. Auten (1933) showed that the deterioration in soil structure following the removal of the forest floor is not due to loss in organic matter from the mineral soil. Ramann (1898) and Lunt (1937) also found that soil compacting followed periodic litter removal, and Stone (1953) was moved to state that when fire is frequent enough to keep soil bare most of the time, deterioration may be rapid. The end results of significantly decreased infiltration are excessive surface run-off and accelerated soil erosion. Mac Kinney (1929) showed that the forest floor prevents, or retards and alleviates, soil freezing, and Hendricks (1941) showed that it greatly decreases the daily range in surface soil temperature through raising the average daily minimum temperature and lowering the average daily maximum temperature. The forest floor also significantly retards evaporation from the surface mineral soil, but on the other hand, it may entirely absorb light rainfalls that might otherwise be partially available for plant growth.

In time when the mineral soil is kept bare of unincorporated organic litter, the loss of reserve humus and nutrients for the mineral layers makes itself felt, but Wittich (1951) demonstrated that this process is relatively slow. He found that the humus content of a

diluvial sandy soil dropped only slightly after 35 years of continuous litter removal. The composition of the humus, however, changed much more rapidly: (1) there was an increase in total nitrogen, but a decrease in the rate of formation of available nitrogen; (2) there was a gradual decrease in the base absorption capacity of the humus (as well as of the inorganic fraction) and a decrease in the amount of easily assimilable bases; (3) there was no decrease in base saturation, however, and the pH went up, especially where the litter was of a low antacid buffering capacity. There was a marked decline in soil organisms, resulting in a deterioration of soil structure (and undoubtedly associated with the lower availability of nitrogen). Available phosphate declined. Moisture capacity was lowered, but this fact was often offset by lowered competition and the greater amount of soil moisture added by light rains during dry periods. According to Wittich, the whole process resulting from continuous litter removal is very complex, with nitrogen deficiency playing an important role.

Jemison (1943a) found that annual litter removal in a pine-oak stand near Asheville, N. C., resulted in slightly but significantly lower diameter growth rates of dominant and codominant shortleaf pines from 10.3 to 13.0 inches d.b.h. after a period of 12 years. Lunt (1951b) found that 19 years of annual litter raking in a red pine plantation caused a slight decrease in growth rate. Lutz and Chandler (1946:188) cited several investigators who showed that annual litter removal ultimately results in reduced growth rates.

Complete burning of the forest floor has the same physical effects as complete removal of it, but the chemical and biological losses are

not so severe. The reserve organic matter and nitrogen are lost, but the mineral nutrients are converted into more soluble forms and move readily into the mineral soil where they invariably cause a rise in pH; once in the soil, they may be utilized by plants or lost through leaching, depending on cation exchange capacity, base saturation, plant activity, and perhaps other factors at the time (Lutz and Chandler, 1946; Kittredge, 1948; Baker, 1950). Unless the fire is exceedingly hot and destructive to the A_1 horizon, there is also an increase in nitrification which, according to Baker (1950), is strikingly high for a year or two and then rapidly falls to the old level. Where there is an extreme raw humus condition, stimulation of nitrification may in itself be justification for prescribed burning, but Baker, as well as Lutz and Chandler (1946), noted that burning for this purpose is rarely justified in the United States.

A final basic consideration, and one that is often ignored, is the possible change in the amount and composition of minor vegetation following burning or removal of the forest floor and the effects that this change might cause in the soil after some time. Heyward and Barnette (1934), for instance, found that annual burning produced an increase in nitrogen in a longleaf pine soil as the result of the abundant grasses and herbaceous legumes promoted by the burning. The effect became apparent, however, only after 8 to 10 years of persistent burning and maintenance of the herbaceous cover.

The above principles would seem to indicate that forest fires might produce results in the soil varying from extreme impoverishment or erosion to perhaps a slight improvement in chemical properties.

Fires which do not consume the lower duff, as is the case for many prescribed fires, will generally not produce any detrimental results that are conspicuous. In order to learn something of the results to be expected from burning under various conditions, it would seem best to consider the published effects of actual fires.

Effects of Fires Outside the Southeastern Region

Flood, Run-off, and Erosion Studies

In the United States, earlier fire effect investigations have to a considerable extent focused on the watershed factors of floods, surface run-off, and soil erosion. This has been particularly true in the mountainous sections of the country, with most studies taking place in the western mountains where fire weather conditions generally become much more hazardous than they do in the east.

The basic soil factor that affects watershed characteristics and that can be radically changed as a result of fire is the rate of infiltration; this in turn is immediately dependent on the protective influence of the forest floor, as explained in the previous section. Usually the reports of these studies do not describe the degree of destruction of the forest floor. However, the fires involved are almost always either wild fires or simulated wild fires, and it can be safely assumed that in most cases forest floor destruction was very near complete if not actually so.

In California, Lowdermilk (1930) found that run-off and erosion were greatly increased by burning. The effect of litter in preventing run-off was most important on fine textured soils, and its influence on run-off and infiltration rate did not cease after it became

saturated. He found that the beneficial effect of the forest floor in maintaining a high infiltration rate far outweighed its detrimental effect in intercepting moisture that would otherwise reach the mineral soil.

Kraebel (1935) studied the effects of 21 storms occurring in 1933 and 1934 in central California on plots that were (1) undisturbed, (2) burned once in 1930, and (3) burned annually for 5 years. Surface run-off occurred for these 3 treatments in the ratio of 1 to 13 to 154. Erosion occurred in the ratio of 0 to 1 to 216.

Rowe (1941 and 1947) emphasized the effect of burning on reduction in soil infiltration rate in the woodland chaparral type in the foothills of the Sierra Nevada Mountains of California. His annually burned plots gave the greatest amounts of surface run-off and soil erosion, his periodically burned plots gave lesser amounts, and his protected plots gave relatively small amounts with erosion being negligible.

Thompson (1935) described extreme erosion effects after a single severe forest fire in the Black Hills of South Dakota. During a single year following the fire, rain gullied the hillsides, while bridges, culverts, and other improvements were damaged or destroyed by run-off and erosion debris.

Eaton (1932), Brown (1943), and Sampson (1944) emphasized the damage that can be done by fires in California chaparral watersheds. Eaton and Brown described excessive erosion following single fires. Sampson reported losses in infiltration rate.

Fritz (1931) related the harmful effects of soil compaction

following fire on heavier soils in the redwood region. Hendricks and Johnson (1944) described accelerated erosion and surface run-off following fire on steep mountain slopes in Arizona. Accelerated erosion followed fire on 42 per cent of the plots in the cutover ponderosa pine type and on 28 per cent of the virgin ponderosa plots in Idaho (Connaughton, 1935). Trimble and Tripp (1949) reported increased erosion and run-off as the result of fire in the lodgepole pine forests of the northern Rocky Mountains. Morris (1935) discussed the effect of fire in accelerating erosion and surface run-off throughout the West.

Blaisdell (1953) reported that wind erosion occurred within a year after prescribed burning in the sagebrush-grass range of the upper Snake River plains. The amount of the erosion varied in proportion with the severity of the burning, but all erosion was stabilized after 2 years as the result of rapid growth of new vegetation.

In the East, watershed effects of fires have been similar to, although not always so spectacular as, effects in the West. Arend (1941), working on loam soils in the Missouri Ozarks, compared infiltration rates on 294 annually burned plots with the rates on 294 plots not burned for 6 years. The average was .8 inch per hour where not burned compared to approximately .6 inch per hour where burned. Stoeckeler (1948) reported that fire in aspen stands of the Lake States consumed all or parts of the L, F, and H layers, reducing the amount of nitrogen for plant growth and decreasing infiltration and water holding capacity of the soil. He stated that severe fires and repeat burns had the worst effects. Auten (1934) compared protected

forest soil, repeatedly burned forest soil, and open pasture soil in the Ozarks. He found average infiltration rates in c.c.'s per second per square foot of 22, 4, and 1 respectively, and volume weights in grams of 523, 654, and 667, respectively. He stated that the divergence would have been greater on steeper slopes.

That fires, even when they are hot, need not necessarily cause reduced infiltration has been demonstrated. Veihmeyer and Johnson (1944), reporting on burning experiments with brush covered grazing plots in California, found infiltration capacity unimpaired by burning. They concluded that surface run-off and erosion would likewise be unaffected. Ferrell and Olson (1952) found little change in infiltration rates resulting from fires overrunning the forest floor in the Western White Pine region of Idaho. A good clue as to a possible means of avoiding reduced infiltration following prescribed burning was given by Youngberg (1953), who stated that the Weyerhaeuser Lumber Company, in order to avoid damage to the humus layer, does not broadcast burn for slash disposal in the Douglas-fir region until after 4 or 5 inches of rain has fallen in the autumn. In the same region, Tarrant (1956) found that slash burning which only charred the surface of the forest floor resulted in an increase in the percolation rate, as measured on saturated volumetric soil samples, in a pumicy sandy loam. Where fire had destroyed the forest floor on the other hand, there was a decrease in percolation rate. The results from a sandy clay loam soil were: no change in percolation where the forest floor was only charred, and a decrease in percolation where the floor was destroyed.

Effect of Fires on the Forest Floor

Most of the authors cited in the previous section did not describe the effects of their various fires on the forest floor. As previously noted, Stoeckeler (1948) reported that fire in aspen stands of the Lake States consumed all or parts of the L, F, and H layers, with severe fires and repeat fires having the worst effects. He also reported that these effects were most serious on light soils because these needed organic matter the most and were already low in productivity. Blaisdell (1953) stated that the litter under the sagebrush of his experimental area was very light previous to burning. This litter was entirely consumed, and the organic matter content, total nitrogen, and moisture equivalent of the top 1/2 inch of soil were significantly reduced at the end of one year after severe burning. Reductions at 2-1/2 inches depth were not significant however. Analyses made 14 years after burning showed that the mineral soil had completely returned to normal.

One might expect that the terrific heat generated by the broadcast slash burns in the Douglas-fir region would cause a maximum of forest floor destruction. Isaac and Hopkins (1937) reported a reduction of organic matter content of duff from 88.53 per cent to 9.72 per cent, and of the top 3 inches of the mineral soil from 5.69 per cent to 3.54 per cent. The residual duff contained a higher concentration but a much smaller total of mineral nutrients than had the original duff. Fowells and Stephenson (1934) found that slash burning may destroy some of the organic matter in the immediate soil surface. Youngberg (1953) showed, however, that by postponing burning until

after 4 to 5 inches of rain had fallen in autumn, good burns could be obtained without complete destruction of the forest floor and with no damage to the topsoil. In many instances, the surface leaf litter was in fact only slightly charred. Tarrant (1956) found less than 5 per cent of the area "severely burned" on 75 field plots in the Douglas-fir region where normal slash burning had been practiced. The remaining area was by implication "lightly burned", which involved only charring the surface of the forest floor.

In California, Vlamis et al. (1955) left an intact layer of duff on the mineral soil by burning when the duff was moist. The forest floor was destroyed only where "clean-up" burns were applied to heavy material. In Arizona, Fuller et al. (1955) found that controlled burning destroyed the duff only under heavy fuels. The residual forest floor left on most of the area after burning was higher in nitrogen, phosphorous, sodium, potassium, and calcium, and lower in carbon-nitrogen ratio than the original forest floor. In Minnesota, a severe wild fire exposed the mineral soil over large areas, consuming from 7 to 26 tons of unincorporated organic matter and causing the loss of 450 to 1500 pounds of nitrogen per acre (Alway and Rost, 1928). On the other hand, another very serious fire in the spruce-fir type of the Adirondack region left a charred forest floor with a median depth of 2 inches. The depth previous to burning had been 14 inches (Diebold, 1942).

It would appear that either mild fires or very hot fires can leave intact duff layers if certain conditions are favorable. The conditions, other than severity of the fire, which would seem to be

most important in determining the amount of forest floor left undestroyed are (1) the original thickness and amount of material in the forest floor, (2) moisture content of the F and H layers, and (3) perhaps the access of oxygen for combustion to the F and H layers.

Effect of Fires on the Physical Properties and Moisture Relations of the Soil

Changes in physical properties and moisture relations of the soil are to a considerable extent related to changes in the protective cover of the forest floor. In this respect, the studies reported here are very similar to those reported under "Flood, Run-off, and Erosion Studies". The division is justified partly on the basis of convenience, but mainly on the basis of the fact that the relationship here to the forest floor is not nearly so clearcut and physical in nature as it is for the run-off and erosion studies. The protective influence of the forest floor is of great importance, but involved also are the indirect effects of fire on soil organisms and on the formation of charcoal.

Soil temperatures after burning

Phillips (1930) found higher temperatures in the day and lower temperatures at night in the 0 to 6-inch layer for burned savanna soils as compared to unburned soils. Hensel (1923) found that burning of grassland caused higher maximum and minimum temperatures, and caused growth to begin earlier in the spring. At 1 inch in the soil, mean maximum temperature was 12° F. higher and mean minimum temperature was 2° F. higher on the burned soil. At 3 inches depth, the increases

were 5° F. and 4° F. respectively. Isaac (1930) and Tryon (1948) reported that charcoal from burns raised maximum temperature at the soil surface to the point where seedling mortality could occur.

Porosity, bulk density, and permeability
after burning

In Arizona, Fuller et al. (1955) reported slightly decreased permeability in the 0 to 2-inch layer after light burning which did not destroy all the duff, and considerably lower permeability after severe burning which consumed all the duff. No tests of significance were indicated in this study.

In the Douglas-fir region, Tarrant (1956) found greatly reduced macroscopic pore space, increased microscopic pore space, decreased total pore space, and increased bulk density following severe slash burning that destroyed the forest floor. His results following light burning which left an intact though charred forest floor were anomalous to the extent that decrease in macroscopic porosity was accompanied by no change or by increases in percolation rates. Light burning caused less decrease in macroscopic pore space than did severe burning, but caused about an equal increase in microscopic pore space. Total pore space increased and bulk density decreased after light burning.

It may be possible that a severe fire can increase permeability of a clay soil under certain conditions. Ehrenberg (1922) reported an increase in penetrability and greater friability of a clay following its subjection to high temperature. Edwards (1938) pointed out the effects of heat in producing good tilth in soils in India.

Moisture relations after burning

Changes in moisture relations after fire depend on changes in the protective influence of the forest floor, changes in organic matter content of the soil, and changes in soil structure.

Bauer (1936) and Sampson (1944) in California and Eden (1924) in England found that moisture was depleted more rapidly in the upper soil layers but more slowly in the lower layers following fire. This was due to greater evaporation from the surface layers and less root occurrence in the lower layers. Phillips (1930) in South and East Africa obtained similar results from the soil of a burned evergreen forest but found no change below 6 inches depth for a burned savanna soil. Beadle (1940) in New South Wales found water holding capacity of a sandy soil not appreciably altered by a ground fire in a Eucalyptus forest.

Isaac and Hopkins (1937) stated that the moisture capacity of the 0 to 3-inch soil layer was reduced by slash burning in the Douglas-fir region. They found that the 25 per cent of the duff not consumed by the fire had lost two-thirds of its original field capacity. Tryon (1948) reported that charcoal raised the water holding capacity of sandy soils and lowered that of clay soils.

Effect of Fires on The Chemical Properties of the Soil

Organic matter, nitrogen, ammonification, and nitrification after burning

Total nitrogen in the soil is most closely related to the soil's content of organic matter. The kinds of nitrogen are most closely related to the decomposition processes in organic matter with ammonification and nitrification being of particular importance. These

two processes are dependent on bacterial life in the soil.

Most of the studies show no change or a decrease in soil organic matter and total nitrogen after fire. Beadle (1940), Griffith (1943), and Lunt (1951a) found no change in soil organic matter after controlled burnings. Fuller et al. (1955), Isaac and Hopkins (1937), Osborn (1931), Perry (1931), and Perry and Coover (1933) found reduced soil organic matter following hot slash fires, wild fires, or frequently repeated fires. The first of these five investigators found no significant change in total nitrogen and therefore a reduction in carbon-nitrogen ratio, the second and third investigators found reduction in total nitrogen, and the last two investigators did not measure this factor. Perry (1931) believed that most of the loss in soil organic matter occurred during summers following fire and was the result of increased decomposition stimulated by heat and an increased pH. Alway and Rost (1928) and Fuller et al. (1955) found no change in total nitrogen after severe burning and light burning respectively. Kivekäs (1939) found a reduction in soil nitrogen after burning. Ferrell and Olson (1952) found nitrogen "higher in 6 cases and lower in 3" following fire in Idaho; it seems likely that there was actually no significant change. The only investigators who found increases in organic matter or total nitrogen following fire were Eden (1924), who found an increase for loss on ignition in the 0 to 1-inch layer, and Jansson (1951), who found "increased nitrogen compounds" in the soils of better Douglas-fir sites in the northern Rocky Mountains. Tryon (1948) increased total nitrogen in a soil by adding conifer charcoal to it.

Often observed following fires is a sudden influx of nitrogenous vegetation, indicating the possibility of increased available nitrogen resulting from increased activity of decomposition organisms. Hesselman (1916-17) observed increased bacterial life and nitrification in the soils of charcoal burning grounds in Sweden. He stated that increased nitrification from a light burning often lasted more than 1 year. Later he established the influence of fire in increasing nitrification and the nitrate supply, and stated that there seemed to be no effect on ammonification (Hesselman, 1918). Sushkina's work (1933) indicated that moderate burning may have a greater effect than intense burning on stimulating nitrification. Fowells and Stephenson (1934) found that a slash fire on a clay soil in the Douglas-fir region stimulated nitrification. They attributed much of the stimulus to the liberation of basic ash materials. They expected the temporary effect to be helpful, but advised that repeated burning cannot improve fertility since productivity depends on gradual mineralization. Isaac and Hopkins (1937) found excellent growth of Azotobacter, seemingly caused by release of calcium ions to the soil, following slash fires in the same region, and found increased nitrate concentration in the 0 to 3-inch soil layer. The carbon-nitrogen ratio was decreased to a 6-inch depth. Kivikas (1939) found slightly increased nitrification and slightly decreased ammonification following fire in Finland. Remezov (1941) and Griffith (1943) found increased nitrification and nitrate supply following fires. Vlamis et al. (1955), using lettuce and barley assay tests, found that the amount of available nitrogen varied directly with the severity of the burn in ponderosa pine type

on Salinas loam and Holland sandy loam in California.

Independent studies of soil microorganisms have yielded rather inconclusive results. Fuller et al. (1955) in Arizona found that the microbiological activity of the soil decreased in direct proportion to the intensity of burning, and that the ratio of bacteria to fungi increased with increased burning of the duff and of the soil organic matter. Corbet (1934) made plate counts of microorganisms in the topsoil after the felling and burning of virgin timber on the Malay peninsula. Immediately after the burning there was a significant increase, but after 1 week the count fell to normal and continued at that point. Dügelli (1938) found that control-burning an old-field spruce stand and mixing the ashes into the soil had no effect on the bacteria count. The mixing of charcoal into a forest soil had no effect on the abundance of bacteria or fungi (Tryon, 1948).

pH and mineral nutrient levels after burning

The literature is monotonous in its revelation of the fact that forest fires increase pH of the mineral soil. Only Beadle (1940) and Blaisdell (1953) found no pH change after burning. The following investigators, who measured pH's within a short time and only once after burning, reported increased pH in the topsoil following fire: Alway and Rost (1928), Eden (1924), Ferrell and Olson (1952), Griffith (1943), Haines (1926), Isaac and Hopkins (1937), Jansson (1951), Kivekas (1939), and Fuller et al. (1955). Fuller et al. reported that the raise in pH was proportional to the severity of the fire. Tryon (1948) caused an increased pH in a coarse-textured soil by mixing

charcoal into it.

Most of the investigators listed above showed that the raised pH levels were accompanied in the topsoil by higher concentrations of available mineral nutrients. Griffith (1943) observed that the higher pH level obtained by burning slash on an agricultural soil in India was due mainly to ash. Haines (1926) found that the per cent of soluble salts increased right after the fire, but leached out in the subsequent few months. Isaac and Hopkins (1937) had a higher concentration of mineral nutrients in the top 3 inches of soil after Douglas-fir slash burning. Jansson (1951) found increased available potassium and more leaching in the upper horizons after fire on Site IV Douglas-fir soils in the northern Rocky Mountains. More abundant available calcium, potassium, and phosphate accompanied increased pH on a Finnish soil that had been burned (Kivekäs, 1939). Fuller et al. (1955) found that severe burning increased available phosphate, exchangeable bases, and total soluble salts down to a depth of 8 to 12 inches in an Arizona soil. Light burning caused an increase in available phosphate, no change in potassium, and a questionable increase in calcium to a depth of 2 inches. The charcoal admixture by Tryon (1948) caused an increase in available phosphate, potassium, calcium, and magnesium.

Investigators who tested pH's and mineral nutrient concentrations more than once and over a period of 2 or more years after fires were able to report on the durability of the raised levels. Perry (1931), who measured pH's one month and 6 months after a disaster-type fire, found indications that the pH was only temporarily raised. Finn (1943) burned organic matter on flats of a sandy soil and of a loam which

were then allowed to set in the open. The pH went up but was back to normal in 1 year, while the added calcium, potassium, and nitrates were leached from both soils. Lunt (1951a) introduced and burned white pine and Scotch pine slash on open areas of Merrimac loamy sand in Connecticut. After 1 to 2 years, the pH showed a slight increase, and available potassium and total soluble salts showed substantial increases. After 7 to 8 years, there were no differences in these respects between the burned plots and the check plots. Eneroth (1928) found that burning for clearing increased pH and that the effect may last for 10 years. Marshall and Averill (1928) found pH's between 7.0 and 8.0 for 58 of 60 samples taken after the 1926 fire in north Idaho from soils that were normally acid. They felt that several years might elapse before normal acidity was regained. After investigating soils where slash had been burned in the Douglas-fir region, Tarrant (1954) concluded that:

1. The more severe the burning, the higher the pH.
2. pH decreased significantly with time since burning. Soils were getting close to original levels 3 years after burning.
3. pH decreased more rapidly where lightly burned than where severely burned.

Perry and Coover (1933) compared frequently burned hardwood areas with infrequently burned areas in Pennsylvania. pH's in the topsoils were about equal, but the frequently burned areas had a higher pH in the B horizon.

Tarrant (1953) heated Olympic loam and Astoria clay loam topsoils,

with organic matter contents of 5 per cent, for 15, 45, and 90 minutes in a muffle furnace. At 600° F., pH of the Olympic loam rose from 5.50 to 6.92, 7.05, and 7.57 respectively. The Astoria clay loam rose from 4.50 to 4.60, 4.87, and 5.31 respectively. Tarrant noted that the more acid soil was more resistant to change. At 900° F. and 1200° F., the Olympic loam went to a pH of 8.5 and the Astoria clay loam went to 5.4 after each of the 3 duration periods.

In three studies where acidity was not measured but nutrient levels were, pH's would undoubtedly have been higher after burning since the mineral nutrient levels seem to have been higher. Fowells and Stephenson (1934) reported that soil mineral nutrients increased after Douglas-fir slash burning, and that the increase would probably last for some time. Kessel (1938) found in Australia that seedlings occurring in and around ash beds grew faster than other seedlings. He attributed the better growth partially to increased nutrients in the soil. Vlamis et al. (1955), using lettuce and barley assay tests, found that phosphate increased in Holland sandy loam in California in direct proportion to the severity of burning. The tests showed negligible phosphate increases in Salinas loam which is a phosphate-fixing soil. Potassium tests were made, but yielded no valid results since potassium was present in the unburned soils in adequate amounts for good growth of lettuce and barley.

The immediate source of soil changes in pH and mineral nutrients after burning is the ash layer resulting from combustion of the forest floor. Ordinarily, this ash layer has very little influence in itself on soil properties, for it is soon dissipated through leaching

and erosion. An unusually heavy ash layer which remains on the soil for some time apparently has a somewhat detrimental effect on germination and growth of trees. Fabricius (1929) tested forest fire ash layers on potted tree seedlings and found germination and early development of all species reduced. The reductions were more striking on loamy soils than on sandy soils. Laurie (1939) reported that teak plantations would not grow in Madras where severe fire had left a thick ash layer. Schmidt (1929) found that a light application of wood ash caused an improvement in germination but a retardation in early growth of Scotch pine.

Growth and development of vegetation after burning

Increased nitrification and mineralization following fire inevitably causes a temporary increase in diversity and growth of vegetation in many instances. Iversen (1956) demonstrated a pattern followed by Neolithic farmers of clearing, burning, planting, and abandonment which clearly took advantage of this fact. A cleared and burned mixed oak area produced much better growth of wheat and barley than did a similar cleared area that was kept hoed and weeded but was not burned. Growth was much less the second year after burning, and the "field" was subsequently abandoned. After abandonment, species appeared on the burned area that did not appear on the unburned clearing. Kivekas (1939) reported improved growth of oats after a burning which had increased the pH and abundance of mineral nutrients in the top 10 cm. of the soil. In very light soils (sands or loamy sands), suddenly released soluble minerals and

nitrate may be dissipated by leaching before plants can make use of them. Thompson (1925) and Alway (1928) found that the burning of slash on the light soils of the jack pine type had no stimulating effect on subsequent crop production. For some crops, yields were actually lowered. It would appear that such soils have an immediate dependence upon organic matter as a source of a regulated supply of available nutrients.

Trees also may be temporarily stimulated in growth as the result of burning. Lunt (1951a) introduced white pine slash to a planting area, burning it on some plots, not burning it on others. Where unburned, the slash caused a 13 per cent growth increase in planted white pine and Norway spruce seedlings over a 5 to 6-year period. Burning of the slash caused a 17 to 18 per cent increase in growth rate of the white pine seedlings but had no effect on the Norway spruce. In another experiment, Lunt (1951b) found that 20 years of annual litter burning in a red pine plantation on Merrimac loamy sand resulted in 8.1 per cent better height growth of the trees and 18.8 per cent better volume growth. In comparison, maintenance of a triple litter supply resulted in 22.3 per cent more height growth and 49.8 per cent more volume growth than produced on the check plots. Shirley (1931) found that the abundance and height growth of aspen suckers were stimulated in the first year after a light surface fire, but that there was no significant effect in the second year (Shirley, 1932). Griffith (1943) obtained the best growth of tree seedlings on a "loamy clay" soil where the slash had been burned and the ash left on the ground. Other treatments produced lower growth rates in the order listed:

burning with the ash removed; no burning, but with ash added; no burning, no ash added. The stimulating effects of the burning and ash treatments were much less pronounced during the second year than they had been during the first year after the treatments were applied. Isaac and Hopkins (1937) found that broadcast burning of Douglas-fir slash stimulated the growth of bracken, senecio, and fireweed. They reported that survival of planted Douglas-fir was poor on clearcut and burned areas, and that 10-year old seedlings were not growing as well on such areas as on unburned areas. In a perhaps more realistic appraisal, Tarrant and Wright (1955) found root and top growth on 2-year Douglas-fir seedlings better where slash had been broadcast burned than where it had been left unburned. Because the increase in growth was relatively small, they concluded conservatively that seedling growth was not inhibited by either light or severe slash burning.

Effects of Fires in the Southeastern Region

Except in very recent years, fire studies outside the Southeastern Region have been conducted generally for the purpose of revealing the results to be expected from the uncontrolled fire. A small proportion of the studies was concerned with broadcast controlled burning of slash resulting from logging or from land clearing. In contrast, most of the southeastern studies have been conducted for the purpose of exploring the possibilities for the use of prescribed fire. This difference in objectives is thought to be possible grounds for separate discussions of these two sets of studies. A further reason for separation was given by Burns (1952) and by

Stone (1953) who felt that observations from outside regions of fire effects on soil properties were of minor value within a given region.

Various studies made in the pine types of New Jersey and Maryland have been included in the Southeastern discussion because the ecological conditions and the objectives involved seem to be more suitable to this category than to the "other region" category.

Flood, Run-off, and Erosion Studies

Specific watershed effects of forest fires have received very little attention in the Southeast as compared to attention given in other regions. Copley (1946) studied surface run-off and erosion resulting from six to seven years of semiannual burning in second growth shortleaf pine-hardwoods in the central Piedmont area of North Carolina. The per cent surface run-off increased from .3 to 20.7 during the period, and annual soil loss increased from .01 ton to 7.8 tons per acre. Dorman and Metz (1952) observed that an accidental fire in July 1950 on the Calhoun Experimental Forest left only a thin layer of ashes and charred organic matter on the soil. Several rains during the succeeding two weeks washed all this away and did considerable damage to the topsoil structure through raindrop impact. A thin layer of new litter from the scorched trees stabilized conditions again after one month, but the authors felt that recovery from the rainfall impact effect would be very slow. Burns (1952) found that 11 to 15 annual fires in the Pine Barren region of New Jersey substantially decreased the infiltration capacity of the soil. However, no ecological harm was done since the sandy soils involved still retained adequate infiltration capacity for preventing excessive

run-off and erosion.

Dorman and Metz (1952) observed that rain following frost heaving of soil often causes severe erosion. Bare soil will heave from frost while soil protected under a forest floor is unfrozen.

Effect of Fires on the Forest Floor

Burns (1952) tested moderate burning (2 annual winter burnings or 3 winter burnings at 3-year intervals) and severe burning (11 to 15 annual winter burnings) on a mor-type forest floor that averaged 2.4 inches in thickness. He observed that moderate burning substantially reduced the 1.3-inch L layer, but only slightly reduced the .6-inch F layer and the .5-inch H layer; there was some increase in mineral soil exposure. Severe burning almost destroyed the entire forest floor and exposed wide areas of mineral soil. Moderate burning caused only a slight loss of litter nitrogen; severe burning caused an almost complete loss of nitrogen in the forest floor. Little and Moore (1949), working in the same upland New Jersey pine area investigated by Burns, observed that removal of much of the forest floor by winter burning favored germination and establishment of pines but discouraged oaks. Buell and Cantlon (1953) reported a marked reduction in litter layers in the New Jersey pine region whenever burning was applied more frequently than once in 5 years.

Little and Moore (1953) found that a severe summer fire consumed most of the forest floor on a lowland pitch pine-hardwood site in New Jersey. They deemed such a hot fire necessary in order to obtain sufficient hardwood reduction on this site for the establishment of

adequate pine regeneration.

Elliott and Pomeroy (1948) observed the effects of a brisk prescribed burn on the forest floor of a clearcut loblolly pine stand on the coastal plain of Virginia. Fire was applied two months after logging which took place on November 7. The L layer was destroyed, but the F layer and the surface root mat remained intact in most places. The F layer was about "50 per cent burned off" only where the fire was exceptionally hot. Lotti (1956a) observed that in flatwoods loblolly stands in South Carolina, pine needle litter could be burned quite readily, but that hardwood litter, or any "flat fuel" litter, was more difficult to burn. He advised that a heavy pine needle rough should be reduced with a winter burn a year or two previous to summer burning in order to avoid excessive damage from the latter.

Heyward (1937) and Heyward and Barnette (1936) compared the forest floor under annually burned conditions in the longleaf pine type with the floor existing after continuous protection for ten years. The annually burned soil had no forest floor, the ground being covered with grasses, some legumes, and other herbs. The protected soil had from 0.75 to 1.5 inches of L, 0.5 to 1.5 inches of F, and a thin, sporadic H, the total forest floor amounting to 20,000 to 55,000 pounds per acre dry weight. The L layer contained .522 per cent nitrogen and the F layer contained .538 per cent.

Effect of Fires on the Physical Properties and Moisture Relations of the Soil

Soil temperatures after burning

Harper (1944), comparing soil temperatures in a longleaf pine

stand that had been protected for two years with soil temperatures in an annually burned stand, found that the temperature averaged higher at 1.5 inches and at 4.5 inches depth in the burned stand. Gum yields were slightly higher under annually burned conditions. Frequently burned soils showed more extreme temperatures at 0 inches and at 3 inches than did protected soils in the Duke Forest (Pearse, 1943). Wahlenberg et al. (1939) found that soil temperatures at 3 inches averaged slightly higher under annual burning than under protected conditions in the longleaf pine type of Mississippi.

Porosity, bulk density, permeability,
and moisture relations after burning

Pearse (1943) reported that moisture supply averaged higher in the top 3 inches of protected Duke Forest soils than in the same soil layer where frequent burning had been practiced. The factor involved here seems to have been increased evaporation of soil moisture after destruction of all or most of the forest floor. Wahlenberg et al. (1939) found porosity, mechanical penetrability, and ability to absorb water "several times greater" for longleaf soils protected from fire and grazing than for soils under annual burning and grazing. In spite of these differences and the temperature differences previously mentioned, these investigators found no differences in soil moisture. Green (1935) also failed to find differences in soil moisture when comparing the effects of eight years of protection against eight years of annual burning in virgin longleaf pine of the southern Mississippi hill country. In contrast, Heyward (1939) found that the actual soil moisture supply for protected longleaf soils in Florida averaged higher

down to 10 inches depth than did the moisture supply in annually burned soils; there were no differences between the two treatments in wilting per cent and in moisture holding capacity of the soil, however.

Heyward (1937) observed that frequently burned longleaf soils were morphologically closer to grassland soils than to forest soils. The perennial grasses produced a dense A₁ horizon with a single-grained and massive structure. Heyward believed this was due to the lack of vigorous soil fauna and exposure of the surface soil brought on by the burning. Protected soils had active fauna and a highly penetrable and porous A₁ horizon, with a fine crumb structure often evident where the texture was sandy loam or heavier.

In contrast to the above, Bruce (1951), using small test fires in southern Mississippi and in northern Florida, found no change in soil characteristics after 13 years. Suman and Halls (1955) tested winter burning at 1-, 2-, and 3-year intervals on imperfectly to poorly drained, relatively infertile sandy soils of the longleaf-slash pine forest of south Georgia. After seven years, they found no effect of burning alone on bulk density of the soil. Burning with grazing caused a significant compaction of the soil. Grazing alone caused slight compaction.

In the New Jersey pine region, Lutz (1934) found the topsoil of the frequently burned Plains more compacted than the topsoil of the less frequently burned Pine Barrens. Burns (1952) reported that moderate winter burning caused no appreciable physical changes in the top 4 inches of sandy soils in the Pine Barrens, but that severe winter burning (11 to 15 annual burns) caused a slight decrease in

bulk density and slight increases in pore volume and field capacity. In agreement with the decreased infiltration rate previously cited, air capacity of the top 1 inch of mineral soil was slightly decreased. Burns did not believe that any of these physical changes were ecologically important on these soils.

Chapman (1942) deduced that prescribed burning at 10-year intervals was necessary to maintain loblolly pine in the pine-hardwood region of Arkansas and Louisiana west of the Mississippi River. He believed that any deterioration in physical soil properties resulting from a single burn would be rectified between burns.

Effect of Fires on the Soil Fauna

The soil fauna burrow and tunnel in the mineral soil, often mechanically reduce organic matter by passing it through their intestines, and mix organic matter into the mineral soil. Forest mulls, or A_1 horizons, owe their existence to soil fauna. Thus when abundant, these organisms have profound effects on both the physical and the chemical properties of soils. For this reason, the discussion of soil fauna is interposed at this point between the discussions on physical and on chemical soil properties following fire.

Heyward and Tissot (1936), comparing long protected longleaf pine soils with frequently burned soils, found that the A_0 horizon of the protected areas had 5 times as many microfaunal forms as the ground cover of the burned areas (which had no A_0 horizon). The top 2 inches of mineral soil in the protected areas had 11 times as much microfauna as were found in the same horizon in the burned areas. Earthworm

abundance was also much greater in the protected areas. The authors believed that the diversified, active fauna were the cause of the striking superiority of the protected areas in penetrability and aeration of the topsoil.

Pearse (1943), comparing frequently burned with protected areas in the Duke Forest, tallied macrofauna in the 0 to 3-inch horizon every 3 months for a period of 5 years. Burning decreased earthworms 50 per cent, and all macrofauna 38 per cent. Pearse attributed these decreases to higher pH, less soil moisture, and more extreme soil temperatures.

Effect of Fires on the Chemical Properties of the Soil

Organic matter and nitrogen after burning

Heyward and Barnette (1934), using paired plots and comparing frequent burning with no burning in the longleaf pine type in Florida, found an increase in nitrogen of .14 per cent in the top 4 to 6 inches of the burned soil after 8 to 10 years. They attributed the increase to the development of a heavy grass cover and the presence of grass roots in the soil. Heyward (1936), working in the same area, found that the organic matter content of the topsoil, as measured by loss on ignition², had also increased as the result of the burning.

²According to Waksman (1938), ignition of the oven-dry soil not only causes loss in weight through volatilizing organic matter, but also causes marked weight loss through volatilizing tightly bound water of the inorganic material. Shantz (1947) felt that the error thus introduced would be especially serious and results particularly misleading for southern soils. Dorman and Metz (1952), however, felt that the southern results using this method had some validity because

Greene (1935), testing 8 years of annual burning against protection in south Mississippi, found 1.5 times as much nitrogen and 1.6 times as much organic matter, as measured by loss on ignition, in the burned areas. He also reported greater numbers of bacteria in the soil of the burned areas. He attributed the increased nitrogen after burning to decaying grass roots or possibly to the more abundant legumes. Wahlenberg (1935) also found that frequent burning increased nitrogen and organic matter in surface soils in the longleaf pine type, and Wahlenberg et al. (1939) stated that chemical properties of longleaf soils were slightly better where burning was practiced. Chapman (1942) reported that 27 years of annual burning in the longleaf type at Urania, Louisiana, produced an increase in topsoil nitrogen that was comparable to that reported by Heyward (1934).

Three investigators in the longleaf pine type found no change or found reductions in soil nitrogen and organic matter following fires. Suman and Carter (1954), working on imperfectly to poorly drained, relatively infertile sandy soils of the longleaf-slash pine type in south Georgia, tested winter burning for 1-, 2-, and 3-year intervals. After eight years, they found no significant changes in the organic matter content of the 0 to 3 and of the 3 to 10-inch soil layers. Barnette and Hester (1930) compared the soil of a virgin pine stand on an island that had been protected for 42 years with the soil

southern workers usually dealt with very sandy surface soils where the loss of tightly bound water of the inorganic phase would be a minimum. The writer inclines to this latter viewpoint, and in addition notes that the error involved should have no effect on comparisons within experiments since it would affect each treatment equally.

of a pine stand 80 miles away on the Florida mainland that had been burned almost annually for 42 years. The top 45 inches of the soil on the island had 60 tons of organic matter per acre more than the soil of the burned area (225 tons vs. 165 tons). The validity of this comparison has been questioned (Dorman and Metz, 1952). Donahue (1942) reported that soils of shortleaf and longleaf areas long unburned contained twice as much organic matter as soils of frequently burned areas, and that summer fires were more destructive of soil organic matter than were spring fires.

In the New Jersey pine uplands, Lutz (1934) found that the A_1 horizons of the frequently burned Plains had lower nitrogen and carbon contents than did the A_1 horizons of the less frequently burned Pine Barrens. However, Burns (1952) found that annual burning for long periods in the Pine Barrens caused an increase in the nitrogen and organic matter contents of the top 4 or 5 inches of the mineral soil.

It would appear that in most instances long repeated annual burning will cause an increase in nitrogen and organic matter in the sandy coastal plain soils of the Southeast. Yet it is equally obvious that this type of burning discourages soil fauna which in the protected forest perform the function of incorporating organic matter into the mineral topsoil. Dorman and Metz (1952) reported that frequently burned areas often actually lack such incorporation. In the face of this apparent contradiction, it would seem that the only explanation is the one offered by Heyward and Barnette (1934) and by Greene (1935) to the effect that the frequent burning maintains an herbaceous ground cover of grasses, legumes, and other plants. The dying roots of these

herbs add organic matter with its proteinaceous nitrogen to the mineral soil, and symbiotic bacteria in the roots of the legumes capture free nitrogen from the air.

It should be remembered, however, that a really long protected pine soil is a rare thing in the Southeast. Virtually all pine areas, even the "protected" ones in burning experiments, have been burned within the past 10 to 20 years. It may well be, as indicated by Barnette and Hester (1930) and by Donahue (1942), that pine soils unburned for 40 or 50 years or more will contain more organic matter and nitrogen than frequently burned soils.

pH and mineral nutrient levels after burning

All investigators who tested frequent burnings for long periods against complete protection obtained increases in pH and in exchangeable bases where they measured these. Barnette and Hester (1930), Heyward and Barnette (1934), Wahlenberg (1935), Wahlenberg et al. (1939), and Burns (1952) obtained increased pH's. All except Wahlenberg, who took no measurements of mineral nutrients, reported increases in exchangeable calcium in the topsoil. However Barnette and Hester, who compared an island soil that had been protected for 42 years with a mainland soil that had been frequently burned for an equal length of time, found the calcium level of the 9 to 45-inch soil layer higher in the protected soil. Wahlenberg et al. reported slightly better chemical properties in general after burning, and Burns reported increased potassium as well as increased calcium. Burns also measured available phosphate but found no change in this nutrient due to burning.

Greene (1935), who tested eight years of annual grass burning in south Mississippi, found that mineral nutrients in unincorporated organic matter were made more quickly available, and that there were no losses due to leaching.

Testing winter burning in south Georgia for 1-, 2-, and 3-year intervals after eight years of treatments, Suman and Carter (1954) found no significant changes in pH, potassium, and phosphate of the 0 to 3 and of the 3 to 10-inch soil layers. Lutz (1934) compared the frequently burned pitch pine Plains with the less frequently burned Pine Barrens of New Jersey as to pH, cation exchange capacity, calcium, and phosphate in the topsoil and found only negligible differences. Burns (1952) found no appreciable change in pH, calcium, potassium, and phosphate in the A horizon of Pine Barren soils in New Jersey after two annual winter burnings or after three winter burnings at three-year intervals.

Fertility and growth after burning

Growth of herbaceous plants is always stimulated after burning of the forest floor. Over an 8-year period, Greene (1935) obtained twice the forage production from annually burned longleaf areas in Mississippi as from protected areas. Wahlenberg (1935) reported that forage plants and corn grew better on frequently burned longleaf areas than on others. Lemon (1946) found more forage plants and greater vigor of growth in forage plants after burning in the longleaf-slash pine type.

Growth of small pines may be either stimulated, retarded, or not affected by fire. Trees, of course, are more limited in growth by

the physical factors of the site than are herbs, and in some cases, additional available nutrients resulting from fire may have no measurable effect on tree growth. At any rate, the net change in growth will reflect an interaction among site factors as modified by fire. The principle was illustrated by Heyward (1955) in the report of a greenhouse experiment on growing slash pine seedlings in burned and unburned longleaf soil. When the physical conditions of the unburned soil were maintained in the burned soil, the burned soil produced the best growth. When the physical conditions of the burned soil were maintained as found in the field, the unburned soil produced the best growth.

Wahlenberg (1935) reported that slash pine seedlings grew better on frequently burned longleaf areas than on protected areas. Bruce (1947) reported on longleaf plots near Urania, Louisiana, that had been burned annually for 32 years, since the trees were 1 year old. After the 200 largest trees per acre on the burned plots reached 10 feet in height, their rate of height growth equaled that of the 200 largest trees per acre on the unburned check plots. Previous to the 10-foot height stage, the trees on the burned plots had lost about 5 years' height growth, or about 6 feet, because of fire defoliation. Small test fires in south Mississippi stimulated height growth of 4-year old longleaf seedlings, but in north Florida on poorer soil, the best growth was obtained in unburned plots (Bruce, 1951). In both cases, local soil differences had more effect on height growth than did fire treatments. Wahlenberg et al. (1939) found the best growth of longleaf saplings in Mississippi where fire was excluded. The diameter

growth of old-growth pines was unaffected by several years of burning. McCulley (1950) reported that slash pines under 3 inches d.b.h. in south Georgia and north Florida were retarded in diameter growth rate by winter burning even when not scorched. Growth returned to normal within 3 years, however, and at any rate, mortality losses from burned and scorched trees were far more important than growth losses. Gum yields from longleaf pine were slightly higher in areas burned for two growing seasons than in areas protected for two seasons (Harper, 1944).

In loblolly pine, McClay (1955) measured the effects on diameter growth of annual summer burning and annual winter burning in a 40 to 50-year old flatwoods stand after 5 years of treatments. There was no significant change in radial growth per tree. The stand had contained a fair hardwood understory which was reduced by the burning, and should have received a stimulus from reduced competition as well as from added soil nutrients. Foliar spraying of the undergrowth also failed to stimulate diameter growth of the pines. McClay felt that stimulating effect might have been produced had a major drought year occurred during the 5-year treatment period.

In shortleaf pine, Jemison (1943b) reported on the effects of single severe April fires on diameter growth in a 30-year pure old-field pine stand and in an uneven-aged pine-oak mixture containing pines 8 inches d.b.h. and over. There was no change in diameter growth of dominant and codominant trees, even though the statistical control was very good and should have removed for the most part the effects of variation among individual trees.

Somes and Moorhead (1954) tested burning and thinning on 4

quarter-acre plots in an old-field shortleaf pine stand of age 38 in New Jersey. Two of the plots were burned 3 times in 8 years; the other two were protected from fire. Based on the 75 largest pines per plot, diameter, basal area, and volume growth were best on the burned plots whether or not they were also thinned. In other words, burning was actually more stimulating to growth than was thinning. In an earlier study, *Somes and Moorhead (1950)* had found that prescribed burning did not appreciably affect crop tree growth in oak-pine stands of the Pine Barren region in southern New Jersey. In spite of higher nitrogen content of the A_1 horizon in the less frequently burned Pine Barren region and of greater topsoil compactness in the more frequently burned Plains region, there were no consistent differences in fertility between the two regions as judged in phytometer studies (*Lutz, 1934*).

Changes in density and composition of
minor vegetation after burning

In southern pines, complete protection of well stocked stands will very nearly eliminate any herbaceous undergrowth. At the other extreme, frequent burning will cause the development and maintenance of a comparatively lush undergrowth of herbs with grasses often being the dominant species. This principle was well illustrated for the longleaf pine type by the "Roberts Plots" near Urania, Louisiana (*Bruce, 1947*), where 32 years of annual burning, commencing with the 1-year seedling stand, was compared with 32 years of complete protection. Both burned and unburned plots were fully stocked in the pine overstory at the end of the period. The burned plots had a good

ground cover of Andropogon divergens (Hack.) Anderss. and A. scoparius Michx.; the unburned plots had no herbaceous understory, but had a fair understory of invading hardwoods instead, while the overstory was dominated by invading loblolly and shortleaf pines. Heyward (1937) found the soils in annually burned longleaf plots to be morphologically closer to grassland soils than to forest soils. Lemon (1949) classified the Andropogons and the Panicums of the longleaf-slash pine forest as "fire-followers", because they built up in numbers and density following a fire. After a few years, they gradually declined if additional burning was not applied, although Andropogons decreased very slowly because of tillering and rhizomatous habits. Common broomsedge (A. virginicus L.) reached its peak density in the second growing season after a fire. Lemon found that various Compositae were also important fire-followers. He concluded that the reaction of any one species to fire depended on its morphological adaptations.

After reviewing the literature at the time, Garren (1943) concluded that fire in longleaf stands decreased the amount of Andropogon virginicus but that A. scoparius remained vigorous. Severe burning decreased all grasses and increased weeds. Garren was possibly concerned with the effect of frequent and severe fires on grass stands that had already reached their maximum development as the result of previous fires.

The Andropogons appear to be "fire-followers" in other forest types of the Southeast as well as in the longleaf pine type. Wells (1928), after studying plant communities of the coastal plain of North Carolina, concluded that continued burning of upland oak-hickory

might eventually bring about a vegetational type in which *Andropogons* would be dominant. Oosting (1944) investigated the vegetational effects of a crown fire and a surface fire both occurring in November, 1931, in an old-field loblolly pine stand. The stand was 35 years old and on a good site in the Duke Forest. Herbs, including *A. virginicus*, showed a temporary increase after both kinds of fire. Sumacs and blackberries also invaded after both types of fire and were apparently more durable than the herbs, but they were gradually disappearing when measurements were taken nine years later. There was a marked increase of poisonivy (*Toxicodendron radicans* Ktze.) and Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.) after surface fire, and Japanese honeysuckle (*Lonicera japonica* Thunb.) was apparently increased by surface fire.

Buell and Cantlon (1953) investigated the vegetational effects of different frequencies of burning, from 1-year to 15-year frequencies, in the oak-pine type on coarse sandy soil in New Jersey. The frequency of herbs increased with the frequency of burning, the densities varying from .3 per cent on unburned plots to 5.5 per cent on annually burned plots. Most of the herb growth was contributed by *Andropogon scoparius* and *Carex pensylvanica* Lam.

Stoddard (1935) found that prescribed fires increased both annual and perennial legumes that were important food plants for upland game in open pine stands of the Southeast. Light fires scarified legume seed and hastened its germination. Late winter was the best time for burning, being neither early enough to cause premature germination nor late enough to destroy already-germinated

seedlings. Perennials sprouted and seeded prolifically after fire even if burned as late as May, and they produced better seed crops as the result of the burning. Garren (1943) cited numerous authorities who found that legumes, as well as Chrysopsis spp., increased following fire in grasslands of the longleaf pine type.

Mortality, kill-back, and sprouting of
small hardwoods resulting from burning

The current use of prescribed fire in the Southeast for the control of small understory hardwoods is of course based at least partially on published research findings. While this paper is not directly concerned with fire effects on tree vegetation, this literature is nevertheless briefly reviewed here because of the unavoidable interaction between fire effects on understory hardwoods and fire effects on minor vegetation and on the soil and the forest floor.

The principles involved in fire damage to small hardwoods seem to be about as follows:

1. Thin-barked species are more susceptible to fire-killing and damage than are thick-barked species. Winter burning in a loblolly pine stand of the Atlantic lower coastal plain readily top-killed all understory southern waxmyrtle, but few hardwoods such as sweetgum were killed back if over 1 inch d.b.h. (Lotti, 1956a). In Texas prescribed burning top-killed all thin-barked species up to 3 inches d.b.h. where the pine litter was uniform (Silker, 1953).

2. Top-killing of a small hardwood is most effective in killing or weakening the plant if done when the plant's carbohydrate reserves are at a minimum. Depletion of carbohydrate reserves in a hardwood

continues in the spring until the photosynthetic area of the newly emerging leaves is adequate to maintain growth. Maximum accumulation of reserves occurs just before the end of the growing season (Woods, 1955). Thus late spring or early summer fires had the greatest weakening effects on understory hardwoods, and when these fires were repeated annually for 2, 3, and 4 years, they killed the rootstocks of a larger and larger proportion of the hardwoods (Chaiken, 1952; Harrington and Stephenson, 1955; Lotti, 1956a). Annual winter burning for 5 years had no effect in diminishing the sprouting ability of repeatedly top-killed hardwoods (Chaiken, 1952).

3. Fires that are hottest near the groundline do the most damage to small hardwoods. In this connection, Lindenmuth and Byram (1948) found that backfires are hotter near the ground than are headfires. In certain humus types, hot groundline fires may kill a large proportion of the hardwood rootstocks outright (Little and Moore, 1953). A gentle and steady adverse wind movement during prescribed burning was stipulated by McCulley (1950), by Silker (1953 and 1955), and by Lotti (1956a) for the purpose of keeping heat near the ground and away from the crowns of overstory pines.

4. The hotter fires top-kill the larger hardwoods. Hence summer fires generally do more damage to hardwoods than do winter fires. Little and Moore (1953) top-killed all of the 1- to 3-inch diameter hardwoods on both upland and lowland in New Jersey with a severe summer burn, and top-killed one-third of the 4- to 6-inch hardwoods on the lowland. A light fire did not kill all of the 1- to 3-inch class. Lotti (1956a) found that winter burning seldom top-killed

sweetgum, black tupelo, and oaks over 1 inch in diameter, and Chaiken (1949) found that winter burning would top-kill hardwoods only up to 1 or 2 inches in diameter. Little and Moore (1949) used repeated winter fires to kill small hardwoods under 2 feet tall in the pine-oak forests of southern New Jersey.

The heat of fires depends upon the fuel type as well as upon the season, of course, with logging slash and deep pine litter giving the hottest fires. Elliott and Pomeroy (1948) reported a brisk prescribed winter burn in the loblolly pine type of Virginia two months after a clearcutting. All hardwoods under 1 inch d.b.h. and 86 per cent of the 1- to 4-inch hardwoods were top-killed; 8.4 per cent of the hardwoods under 1 inch did not resprout. Lotti (1956a) found that a heavy pine needle rough burned with too much heat for a safe summer fire and had to first be reduced with a winter burn. Hardwood litter burned with more difficulty than pine. Silker (1953) found that fires in uniform pine litter, as in plantations, were most effective in hardwood killing. Hardwood litter was difficult to burn at all. Later Silker (1955) reported that prescribed burning of older, partially cut pine-hardwood stands had only a limited effect in killing small hardwoods. Backfires could not be successfully maintained in the fuel of these stands in the fall of the year, and "strip headfires" had to be used.

5. Reduction of hardwoods with a single fire is usually temporary, and the net result is often an increased coverage of hardwoods after a very few years. Thus Brender and Nelson (1954), after cutting and burning a 19 per cent cover of small hardwoods in the Piedmont following clearcutting of the shortleaf pine overstory,

found that the reduction in the amount and height of shade lasted only 2 years. After 6 years, the frequency and amount of hardwood shade in the 1- to 4-foot height class was greater than for the control. Nine years after an accidental fire in a pure loblolly stand of the Duke Forest, Oosting (1944) found that crown fire had changed the type to pine-hardwood, and surface fire had caused a great increase in numbers and sizes of hardwoods in the understory. In the loblolly type of the lower coastal plain of North Carolina, Wenger (1955) compared increase in hardwood cover after clearcutting and burning with normal increase in hardwood cover after clearcutting alone. Burning caused a faster rate of increase on all well-drained soils, but retarded the rate of increase on poorly drained soils with plastic subsoils; the burning influence seemed to last approximately 3 years in both cases. Wenger thought that probably increased mineral nutrients and nitrates stimulated growth on the well-drained soils, but that hardwoods on the poorly drained soils suffered from decreased oxygen after fire.

Possible Results Due to Changes in Forest Composition

In the Southeast, fire and poisoning are often aimed at maintaining pine stands free of hardwoods or at converting pine-hardwood types to pure pine types. Thus the problem of forest composition effects is imposed upon that of burning effects. More specifically, many foresters are concerned with the possibility of site deterioration as the result of growing pure pine instead of pine-hardwood mixtures (Appelquist, 1953; Stauffer, 1956). Stone (1953) felt that this

concern might well be unfounded in the Southeast, but that it would be influential nevertheless in the absence of evidence showing its lack of validity. In a prescribed fire study of only four or five years' duration, the immediate burning effects will of course mask out the more slowly developing composition effects. Thus it is not expected that forest composition effects will play a role in the study reported herein.

The thought of many American foresters on the possibility of site deterioration resulting from pure pine composition is perhaps best expressed in one of their standard textbooks. Toumey and Korstian (1947) assigned several important biological advantages to mixed stands and none at all to pure stands. They stated that mixed crops are more successful on poor sites and generally maintain a higher soil quality.

This attitude apparently stems from old European experiences with Norway spruce plantations (Baker, 1950). According to Bühler (1922) pure Norway spruce plantations were given widespread establishment in Europe, even outside the tree's natural range, during the nineteenth century. Weaknesses developed in many of these plantations as they matured, weaknesses usually connected with the low buffering capacity and the low calcium content of the spruce litter and its tendency to promote raw humus formation in cooler climates. European reactions of the late nineteenth century tended toward generalizations on mixed and pure stands that are still accepted by many Americans today. European foresters of today, however, tend to avoid generalizations on this subject.

Quantity and Quality of Litter Produced
by Hardwoods as Compared to Pines

Lutz and Chandler (1946) made numerous citations from both European and American literature to show that the weight of dry organic matter returned annually to the soil by stands of different species in the same general environment is about the same. In the Piedmont region of South Carolina, pine, pine-hardwood, and hardwood stands each produced about 4400 pounds per acre of annual litter fall (Metz, 1952 and 1954). This equality among species in quantity litter production makes the qualities of the various kinds of litter directly comparable.

Hardwood litter is generally higher in all mineral nutrients than is pine litter (Lutz and Chandler, 1946) and is particularly higher in calcium (Coile, 1940; Auten, 1945; Metz, 1952 and 1954). Litter from some of the dry-site oaks is definitely poorer in calcium than other hardwood litter, but is still richer than litter of southern pines (Coile, 1940; Lutz and Chandler, 1946; Metz, 1952; Applequist, 1943).

The antacid buffering capacity of hardwood litter is superior to that of pines (Coile, 1940; Lutz and Chandler, 1946).

Nitrogen content of litter is much more variable than calcium content, and distinctly reflects the available nitrogen level in the soil (Mitchell and Chandler, 1939; Finn, 1953). However several investigators have established a general superiority of hardwood litter over pine litter in nitrogen content (Coile, 1940; Auten, 1945; Metz, 1952 and 1954).

Scott (1955) found that the subordinate vegetation under the transition hardwood type and the white pine type produced litter with higher contents of mineral nutrients and of nitrogen than the litter from the dominant vegetation. The subordinate vegetation accounted for 15 per cent of the total weight of litter produced.

Properties of the Forest Floor and of the
Topsoil under Hardwoods as Compared
to under Pines

As stated by Lutz and Chandler (1946), high calcium content in the litter will increase calcium content of the soil, reduce acidity, favor mull formation, and stimulate the fauna and flora of the soil. Since hardwood litter is generally higher in calcium than pine litter, the forest floor and the topsoil under hardwoods should be favored in like manner.

Coile (1940) found that the rate of decomposition in litter varied directly with its content of nitrogen and calcium and with its antacid buffering capacity: litter of dogwood, hickories, sweetgum, and yellow-poplar decomposed rapidly and completely; litter of pines and oaks decomposed slowly and incompletely. Investigating forest floor and soil properties for the various stages of succession following abandonment of cultivated land in the Piedmont,³ Coile found definite mull development only under older loblolly pine stands having a well established hardwood understory made up principally of such

³Oosting (1938, published in 1942). The main stages in succession were: (1) broomsedge; (2) young loblolly pine; (3) old loblolly pine with hardwood understory; (4) white oak-black oak-red oak climax.

species as yellow-poplar, sweetgum, black tupelo, and dogwood. Earlier stages of succession tended toward imperfect mors and thin mors; the climax white oak-black oak-red oak forest had a humus type described as a root mor, with a mat-like H layer 0.5 inch in thickness. Topsoil in the pine-over-hardwood stage had slightly more nitrogen, a lower carbon-nitrogen ratio, more calcium, and a higher percolation rate than did the topsoil in the other stages. There was no difference among the various stages of succession however in such physical soil properties as volume weight and air capacity. The old pine-over-hardwood stage had the greatest thickness of forest floor, but McGough (1947), working later in the same area, obtained the greatest weight of forest floor, 26,873 pounds per acre, in an earlier stage when the pine was about 55 years old.

Comparison of McGough's maximum forest floor weight given above and other maximum forest floor weights of the Southeast with forest floor weights of up to 193,000 pounds per acre (Lutz and Chandler, 1946) obtained on northern podsoils reveals that litter decomposition rates for all species in the Southeast are comparatively rapid. Auten (1941) found that the weights of the forest floors under shortleaf pine, chestnut oak, and white oak respectively in southern Ohio were 26,968, 19,661, and 14,400 pounds per acre. The amount of nitrogen per acre tied up in each was 409, 377, and 227 pounds respectively. Metz (1954) found forest floor weights of 20,000, 16,000, and 13,000 pounds per acre under pine, pine-hardwood, and hardwood stands respectively in the South Carolina Piedmont. The nitrogen tie-up was 146, 154, and 121 pounds per acre respectively. Topsoils under

the hardwood stands had the best mull development, but it should be noted that two of Metz's three hardwood stands were composed principally of yellow-poplar and hickories, both of which have calcium-rich litter. Bulk density was lowest, and organic matter and nitrogen were highest in the topsoil under the hardwood stands.

Effects of Hardwood Mixtures on Pine Yields

Admixtures of hardwoods of many species into pure southern pine stands will tend to improve properties of the forest floor and of the topsoil. Maintenance or development of pure pine stands cannot be said to cause site deterioration, however, unless the changed soil properties cause a reduction in yield. There is no evidence that such is the case in the Southeast (Chaiken, 1949). Topographic position, the nature of the subsoil, and depth to the subsoil seem to be of predominating influence in determining yields of southern pines (Hodgkins, 1956); the soil and forest floor properties that are improved with hardwood litter seem to be adequate under normal stands of pure pine and do not actually need such improving as far as yield is concerned (Stone, 1953). Even if the yield potential of a pure pine stand were increased through the introduction of hardwoods, there would still be the question as to whether or not the value yield of hardwood plus pine would equal the value yield of pine alone from the pure pine stand. For while hardwood litter contributes more to the soil than pine litter, hardwood trees take more from the soil than do pine trees, and in addition when they are in the overstory, hardwood trees occupy space that could otherwise be occupied by the generally

more valuable pines.

Lutz and Chandler (1946) refused to be concerned over so-called site deterioration from pure stands where the species was adapted to the site and given proper silvicultural care. They stated that changes in composition caused changes in the soil, but that these did not necessarily constitute deterioration. Baker (1950) felt that the mixed vs. pure stand question was largely academic in America and that natural pure stands seemed to have no outstanding weaknesses. Stone (1953) expressed surprise that views based on European experience with spruce in northern podsoles should have received such serious consideration in the Southeastern region.

Hepting and Jemison (1950) and Campbell et al. (1953) have theorized that the encouragement of hardwoods will help combat little-leaf disease in shortleaf pine. It appears that littleleaf disease is most common on soils with little or no surface depth above zones of poor internal drainage, as is often the case for badly eroded old fields. The disease seems to be caused by a nitrogen deficiency due to the killing of fine roots in such soils by the fungus Phytophthora cinnamomi. These investigators advocated the use of soil-building hardwoods to offset some of this effect.

Conclusions from the Literature

In the conclusions reached below, due account has been taken of conclusions from the literature on fire effects reached by Chaiken (1949), by Burns (1952), and by Dorman and Metz (1952).

1. The most serious soil damage that can occur after burning

is excessive run-off accompanied by accelerated erosion due to rain-drop impact on exposed mineral topsoil. Flat soils of a coarse texture can be repeatedly and frequently exposed without serious damage of this kind. Damage on sloping soils will depend on (a) the degree of slope, (b) the time allowed for recovery from previous exposures, (c) the time after exposure until a new litter fall occurs, (d) the texture of the surface soil, and (e) the structure of the surface soil as affected by past use, particularly by past cultivation and erosion. The normal sand, loamy sand, or sandy loam topsoil in the Upper Coastal Plain should be able to withstand infrequent exposure, say for seedbed preparation purposes, even on fairly steep slopes. The exact amount of exposure it could withstand is a problem in research.

2. A "hot fire" need not necessarily consume the entire depth of the forest floor with subsequent exposure of the mineral soil. The proportion of the forest floor consumed depends upon the following:

(a) The amount of fuel available. Under open forest canopies, or with a short elapsed time since the last fire, a given set of prescribed conditions for burning is more apt to cause complete destruction of the forest floor. (b) The prescribed weather and fuel moisture conditions for burning. The stipulated time since the last good rain is the most important condition because this factor controls the moisture content of the lowermost duff layers. Summer fires are more destructive than winter fires. The weather and fuel moisture conditions as affected by the microclimate are also very important. (c) The kind of fuel. Flat fuels, such as oak leaves after some weeks on the ground, will not burn as deeply as straw-like fuels such as

pine needles.

3. Frequent exposure of the mineral soil will cause physical changes in the topsoil not associated with raindrop impact or with organic matter content of the soil. These include a lessening of penetrability, macroporosity, and total porosity, and an increase in bulk density. The cause of the changes seems to be lessening of soil macrofaunal activity. For normal southern topsoils of light texture, a single exposure or occasional exposures will probably not produce measurable changes. Frequent exposure will produce obvious changes in sandy loams.

4. Exposure or near exposure of the surface mineral soil will cause increased moisture losses to a depth of 3 to 10 inches. This loss will be due to increased soil evaporation or to transpiration from minor vegetation stimulated by burning.

5. Exposure or near exposure of the surface mineral soil will cause more extreme soil temperatures and increased mean temperatures to a depth of 4 or 5 inches. These effects will be minimized under a dense tree canopy.

6. Combustion of organic matter within the mineral soil occurs only during very hot fires and then only beneath heavy fuels such as logs or slash accumulations. Losses of organic matter in this way are not apt to be significant in any prescribed burning.

7. Infrequent prescribed fires have no effect on organic matter and probably have no effect on total nitrogen in the mineral soil of southern pine stands. Frequent burning will cause increased organic matter and total nitrogen in the soil as the result of the stimulation

of an herbaceous undergrowth, particularly of legumes. It remains to be seen whether or not this effect will hold for soils of the Gulf Upper Coastal Plain region.

8. Nitrogen in compounds in the forest floor is freed to the atmosphere during fire. However, for the southern pine areas investigated so far, this loss has generally not been reflected in the mineral soil. Instead the mineral soil may show a net gain (see number 7 above). Dorman and Metz (1952) believed that nitrogen lost from the forest floor during a fire might be lost anyway during normal decomposition of organic matter.

9. Some of the soluble mineral nutrients deposited in the ash may be lost through leaching, but apparently in southern soils, at least a large proportion are saved in sandy loams. In sands, most of the ash nutrients may be lost. Southern pine soils are normally very low in base saturation when unburned, and so can absorb and hold a considerable number of cations where their cation exchange capacities are at all appreciable. Also, southern soils usually have a high "anion exchange capacity" for the phosphate ions due to the presence of abundant iron and aluminum compounds in moderately to strongly acid mediums. Finally, plant roots are active in southern soils during all or most of the year, and will absorb some ions more rapidly when their concentration becomes higher in the soil.

10. A frequent burning program tends to perpetuate a higher pH and a higher level of exchangeable bases for an indefinite length of time. With one fire only, the rise in pH and in mineral nutrient levels will be in direct proportion to the severity of the burn, with

light burns often not showing any effects at all. Cations in excess of the soil's cation exchange capacity may be lost by leaching within months if a quick growth of sprouts and herbs does not utilize them. On the other hand, higher pH and nutrient levels resulting from one burn may persist for as long as 10 years. The relations involved are not at all understood, and it may be that a burned condition of the forest floor, in contrast to an unburned condition, is conducive to an entirely new regime of decomposition and leaching such as will maintain a higher level of base saturation in the soil.

11. Minerals moving into the soil from a burned forest floor stimulate nitrifying bacteria and cause an increase in nitrate nitrogen for a year or two after a fire. This commonly accepted phenomenon has not actually been proven for the Southeast, but there is no reason to suppose that it does not occur in that region just as it does in others. Indeed all bacteria in the topsoil under southern pines may be stimulated since pH, mineral nutrient supply, and temperature improve for them after fire. They are not robbed of food material since there is normally little or no incorporation of the forest floor into the mineral soil; they may actually receive more food material eventually from decaying roots of a new herbaceous undergrowth. The only factor that might become less favorable for soil bacteria is the soil moisture supply.

12. The diversity and growth of herbs and lesser woody species increase after fire. This seems to be a direct response to increased mineral nutrients and nitrate in the soil, but under pine must also be related to changes in the seedbed and to control of the smothering

effect of accumulated litter.

13. Smaller trees, being more responsive to physical characteristics of the soil than are herbs, may slightly increase or slightly decrease in growth rate following prescribed fire. Their response may depend on whether a slight chemical improvement or a slight physical deterioration of the soil is more significant to them. Burning which leaves part of the forest floor intact should cause no loss in growth rate. Larger trees are not known to respond one way or the other to prescribed fire (assuming no direct burning injury to the tree).

14. The kill of small hardwoods by fire will depend on species and diameter of trees, season of burning with reference to carbohydrate storage in roots, heat of fire at the groundline, and frequency and repetition of burning. The heat of fire at the groundline will depend on fuel type and amount, the prescribed weather conditions for burning, the burning techniques (headfire or backfire), and the microclimate as affected by local cover and topography. A single reduction of hardwoods by burning is usually temporary in nature and within a few years often results in increased hardwood cover. Frequent winter reductions seem to have no permanent effect.

15. Topsoil under pure southern pine stands can be improved physically and chemically with the addition of litter from certain hardwood species. However, extensive site evaluation studies in the Southeast have established significant relationships for just one topsoil property with pine yield, that property being thickness of the topsoil. If fertility values could be established for certain

hardwood species, there would still remain the problem of obtaining equal or better total value yields while using some of the growth energies of the site to produce the less valuable hardwoods themselves.

LOCATION AND DESCRIPTION OF EXPERIMENTAL AREA

Location, Geology, and Topography

The Fayette Experiment Forest is located approximately 60 miles west of the city of Birmingham in the Upper Coastal Plain region of Alabama at latitude 33 degrees 48 minutes north and longitude 87 degrees 48 minutes west. The Forest is in Fayette County and is 10 miles north of the city of Fayette.

The geological formation is Tuscaloosa, which is a part of the Upper Cretaceous sediments and is the oldest formation in the Upper Coastal Plain region.⁴ This formation typically consists of light-colored, irregularly bedded sands, clays, and gravels, with the gravels occurring chiefly in the basal beds of the formation. Throughout its extent in Alabama, the formation normally expresses itself as a decidedly hilly upland (Adams et al., 1926).

The experiment forest of 1380 acres lies between 350 and 500 feet above sea level and has a strongly hilly topography. Level to gently sloping land occurs mainly on broad ridge tops and constitutes less than 20 per cent of the total area. Narrow bottomland areas along intermittent creeks constitute less than 10 per cent of the total area. The remaining area is made up of moderate to steep slopes of various exposures.

⁴Just 10 miles east of the Fayette Experiment Forest places one within the still older Carboniferous Pottsville formation of shale and sandstone in the Southern Appalachian region.

Soils

The soils of the Fayette Experiment Forest belong to the red and yellow podzolic group typical of the warm, humid climate of the Southeast.⁵ The soil types have been mapped by Brackeen (1953) and are shown in Figure 1. Descriptions of the soil types follow.

1. Atwood very fine sandy loam.

- 0"-1" Dark gray very fine sandy loam.
- 1"-8" Dark reddish brown, friable, very fine sandy clay loam being slightly sticky when wet. Strongly acid.
- 8"-40" Brownish-red, friable clay loam exhibiting considerable stickiness when wet. Strongly acid.
- 40+" Same as above but contains some splotches of yellow, brown, and gray. In some locations it is more friable than above horizon but is generally heavier, more sticky, and plastic.

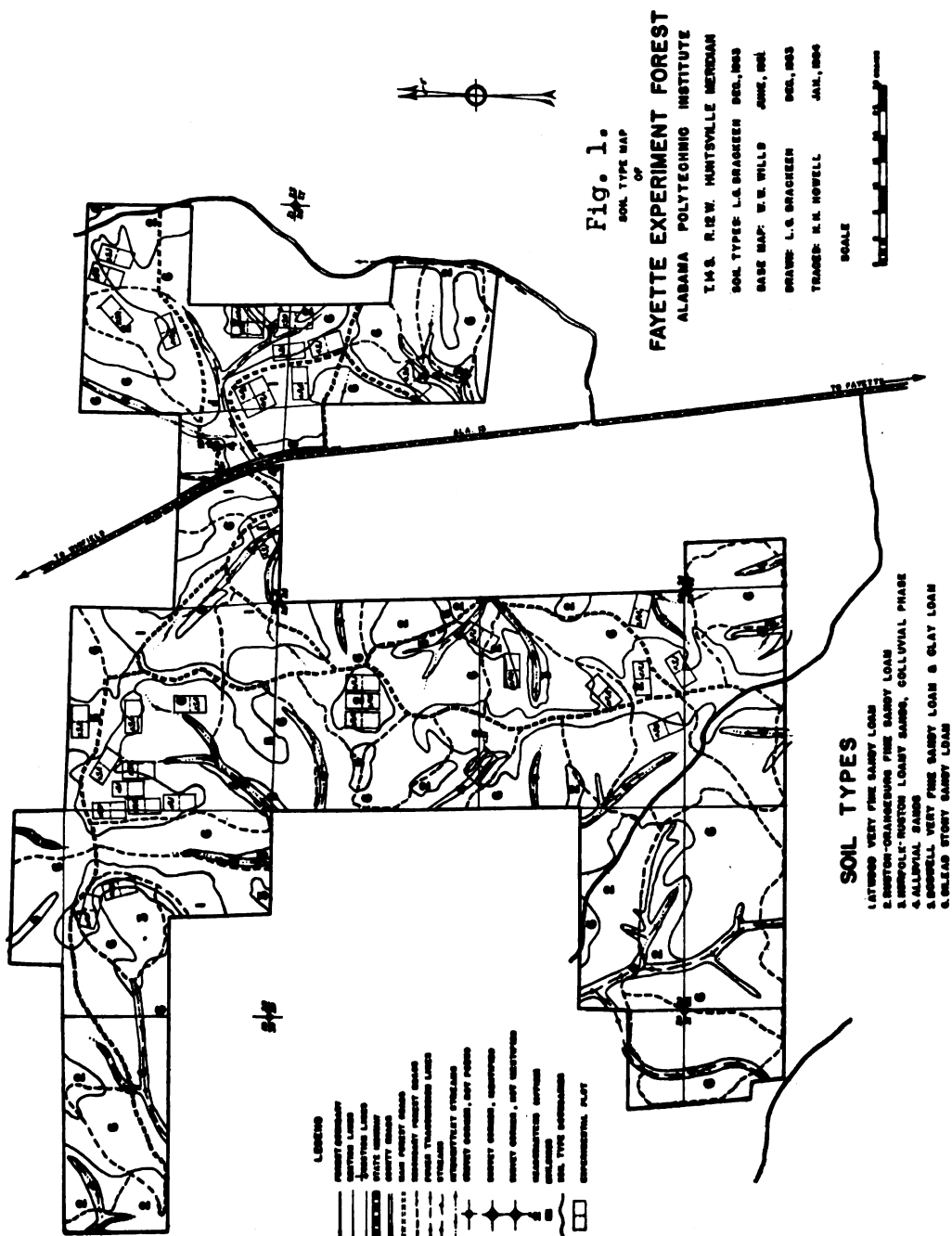
NOTE -- This is an important soil being especially good for the production of cotton and other farm crops as well as pasture or forestry.

2. Ruston-Orangeburg fine sandy loams. These soils are very similar, the Orangeburg being slightly redder than the Ruston. Small areas of Atwood soils that were too small to separate on the map constitute the lower lying portions. The predominant characteristics are as follows:

- 0"-2" Brownish-gray loamy sand containing considerable organic matter.
- 2"-15" Brownish-yellow, loose, friable fine sandy loam. Acid in reaction.
- 15"-50" Red to brownish-red, friable fine sandy clay loam. Acid in reaction.
- 50+" Red friable sandy loam containing some splotches of yellow and brown. More friable than above horizon.

NOTE -- This is an important soil for farm crops as well as forestry.

⁵According to "Soils and Men" (U. S. Department of Agriculture, 1938), red and yellow podzolic soils are strongly leached, acid in reaction, and low in organic matter and mineral plant nutrients. Surface soils are of light color and sandy, and subsoils are heavier, tougher, and are red, yellow, or mottled in color.



3. Norfolk-Ruston loamy sands, colluvial phase. Norfolk soils predominate and the predominant profile is as follows:

- 0"-2" Gray loamy sand containing considerable partially decomposed organic matter.
- 2"-50" Gray, loose, friable loamy sand. (This horizon varies in depth from 30 inches to as much as 60 inches.) Acid in reaction.
- 50+" Brown to brownish-yellow, friable fine sandy loam. In a few locations this horizon is a heavy, dense, compact clay. Acid in reaction.

NOTE -- This soil would be good for the production of corn, however, its sloping relief coupled with its poor soil binding qualities makes it very subject to gully erosion. Its excellent qualities for the production of timber is due to the lateral movement of moisture through the soil together with the lower lying strata of heavier soils in which the roots are anchored. Roots no doubt penetrate to greater depths in these areas than in any other areas on the forest and certainly much greater than in areas of 5 and 6.

4. Alluvial sands. This classification consists of a mixture of sands and organic matter which are generally 5 or more feet thick. Sands from the ridge tops have, in times past and during current freshets, been transported by stream and gravitational action and deposited on these stream bottoms. Most areas overflow several times each year.

5. Boswell very fine sandy loam and clay loam. This soil is similar to Susquehanna, differing mainly in being redder. It has the following characteristics:

- 0"-1" Brown very fine sandy loam or clay loam containing considerable organic matter.
- 1"-4" Reddish brown very fine sandy loam or clay loam. Sticky when wet. Very acid.
- 4"-20" Red, heavy, sticky, plastic clay. Very acid.
- 20+" Mottled, red, gray and yellow heavy, sticky, plastic clay becoming grayer with depth. Very acid.

NOTE -- This soil would be especially good for the production of pasture grasses. Its tilth is too difficult for row crops. Tree roots are no doubt shallow.

6. Gilead stony sandy loam. The most outstanding characteristics of this soil are its strongly rolling relief, its

stony condition, and its variable surface soil depths. It occurs on slopes of 5 to 20 per cent. Stone fragments which vary in diameter from 4 to 12 inches and in thickness from 1 to 4 inches are common to most areas. These stone fragments are iron impregnated. Iron was dissolved by rain water in the surface sandy soil which later precipitated on top of the underlying impervious clay strata to form these rocks. The surface soil depth varies from 0 to as much as 15 inches, depending upon the severity of erosion. As a whole, erosion has been greatest along ridge crests and less severe on descending slopes. This difference is evidenced in timber growth but changes were of such a gradual nature that soil delineations were difficult to impossible. In general the soil has the following characteristics:

- 0"-2" Gray sandy loam containing some organic matter.
- 2"-10" Yellowish-brown friable fine sandy loam. Acid in reaction.
- 10"-20" Brownish-yellow firm and dense but friable fine sandy clay. Very acid.
- 20+" Brownish-yellow firm, dense fine sandy clay loam mottled with some red, yellow and iron splotches. Generally gets more friable with depth. Very acid.

NOTE -- This soil tends to have poor moisture relations due to rapid runoff resulting from steep slopes and slow water penetration. Furthermore, there is considerable doubt that tree roots are able to penetrate to very great depths, particularly on the more eroded areas.

Mechanical analysis according to the method of Bouyoucos (1936) yielded particle size class distributions for typical soil profiles as shown in Table 1. The Boswell very fine sandy loam normally has about 8 inches of very fine sandy loam over a clay subsoil, but due to past sheet erosion of this soil type in the experimental area, only truncated versions of the normal profile could be found. The amount of gravel and stone in the Atwood and the Norfolk-Ruston soils is less than 1 per cent. The Ruston-Orangeburg soils normally contain 5 to 10 per cent gravel and stone. The topsoils of the Boswell and of the Gilead soils usually contain over 20 per cent gravel and stones, but the subsoils have only around 5 per cent.

TABLE 1.--Particle size class distribution of typical soil profiles^a

Soil Type	Horizon Depth	Sand	Silt	Clay	Textural Classification ^b
	<u>Inches</u>	<u>Per cent</u>	<u>Per cent</u>	<u>Per cent</u>	
Atwood very fine s.l. ^b	0-1	76.9	17.3	5.8	l.s. to s.l.
	1-8	52.8	24.4	22.8	s.c.l.
	8-40	19.6	28.0	52.4	c.
	40+	6.8	27.0	66.2	heavy c.
Ruston-Orangeburg fine s.l.	0-2	78.8	15.9	5.3	l.s.
	2-15	76.5	15.6	7.9	s.l.
	15-50	68.6	7.9	23.5	s.c.l.
	50+	75.1	4.4	20.5	s.l. to s.c.l.
Norfolk-Ruston l.s.	0-2	86.9	8.8	4.3	s. to l.s.
	2-50	85.9	8.4	5.7	l.s.
	50+	71.2	7.8	21.0	s.c.l.
Boswell very fine s.l.	0-6	45.9	35.2	18.9	l.
	6+	17.6	33.6	48.8	c.
Gilead stony s.l.	0-2	79.2	15.5	5.3	l.s.
	2-10	80.8	10.2	9.0	l.s. to s.l.
	10-20	67.1	6.3	26.6	s.c.l.
	20+	66.6	7.8	25.6	s.c.l.

^a After particles larger than 2 mm. in diameter have been removed.

^b Abbreviations: c.-clay, l.-loam or loamy, s.-sand or sandy.

Climate

The climate can be characterized as generally hot and moist, but at this northerly latitude in Alabama it has definite continental properties. The average number of frost free days is 231 (Hocker, 1955). Temperatures are cool in the winter and hot in the summer, with the relative humidity generally being high. The annual precipitation is high and moderately well distributed, but there is a tendency toward heavier precipitation in the winter months and decidedly lighter

rainfall in the late summer and early autumn when prolonged drought periods of 3 or 4 weeks or more are not uncommon. Temperature and precipitation data for Tuscaloosa, which is approximately 50 miles south of the experimental forest, are presented in Table 2.

TABLE 2.--Average monthly and annual temperature and precipitation data from Tuscaloosa and from Winfield, Alabama^a

Month	Temperatures (°F)			Precipitation (in.)		No. Days ≥ .5" Ppt.
	Ave.	Max.	Min.	Tuscaloosa	Winfield ^b	
Jan.	47.0	57.7	36.9	5.31	8.50	3.8
Feb.	49.5	60.5	38.6	5.43	7.31	4.1
Mar.	55.7	67.4	43.7	6.43	7.73	4.2
Apr.	64.0	76.3	52.1	4.55	3.54	3.1
May	71.8	83.8	60.2	4.37	3.42	3.2
June	79.8	91.4	68.5	4.03	3.34	2.4
July	81.7	92.7	70.8	5.01	4.40	3.5
Aug.	81.2	92.5	69.9	4.12	4.66	2.7
Sept.	76.6	88.5	65.1	2.83	3.88	1.9
Oct.	65.5	78.8	52.7	2.79	1.23	1.5
Nov.	54.1	66.4	42.4	4.45	5.38	2.9
Dec.	47.6	58.1	37.2	5.54	5.26	3.7
Ann.	64.5	76.2	53.2	54.86	58.65	37.0

^a All data except the Winfield precipitation data are from Tuscaloosa and were compiled from U. S. Weather Bureau statistics for the period 1921 through 1950 (Hocker, 1955).

^b The Winfield precipitation data are based on the 6-year period from July 1, 1947 to June 30, 1953, and were compiled by the Agricultural Experiment Station of the Alabama Polytechnic Institute (1953).

Precipitation data from Winfield, 8 miles north of the forest, are presented in the same table for comparison. The Tuscaloosa data are averages for the 30-year period from 1921 through 1950; the Winfield data are averages for the 6-year period from July 1, 1947, through June 30, 1953.

At the Fayette Experiment Forest, unusually severe droughts occurred in the late summers and early falls of 1953, 1954, and 1955. Moreover the total rainfall was deficient for at least 1954 and 1955. In Table 3, the 1954 and 1955 monthly precipitations at the Forest⁶ are presented along with the 1947-53 Winfield average monthly precipitations from Table 2. The Winfield data reveal that the most critical rainfall period is from September 11 through October, during which the mean monthly precipitation is normally only 1.84 inches. The mean monthly precipitations in the Forest for this period in 1954 and 1955 were even lower than this figure being respectively 1.66 inches and 0.99 inches.

Succession and the Climax Forest

The general nature of the climax forest vegetation is abundantly evident today, for much of the area, including even some of the gentler slopes, has never been cleared for agricultural purposes. The upland climax is dominated by species of oaks and hickories, with the exact composition probably being determined mainly by available soil moisture. The principal oak species, progressing from the moister

⁶The Fayette Experiment Forest did not install a complete weather station, including a rain gauge, until 1954.

TABLE 3.--Average monthly precipitations at Winfield, Alabama, 1947-1953, and monthly precipitations at the Fayette Experiment Forest for 1954 and 1955

Month	Precipitation (in.)		
	Winfield 1947-53	Fayette Forest	
		1954	1955
January	8.50	8.01	4.99
February	7.31	2.55	6.61
March	7.73	4.07	4.08
April	3.54	4.40	5.76
May	3.42	2.38	4.30
June	3.34	1.28	2.41
July	4.40	1.85	7.02
August	4.66	2.27	2.29
September	3.88	1.42	0.07
October	1.23	1.51	1.58
November	5.38	4.41	4.71
December	5.26	4.35	1.39
Total	58.65	38.50	45.21

site oaks to the drier site ones, are northern red oak (Quercus rubra L.),⁷ white oak (Q. alba L.), black oak (Q. velutina Lam.), scarlet oak (Q. coccinea Muenchh.), southern red oak (Q. falcata Michx.), post oak (Q. stellata Wangenh.), and blackjack oak (Q. marilandica Muenchh.). The principal hickories, found on all sites except the very driest,

⁷ Names of trees are in accordance with the U. S. Forest Service Check List (Little, 1953).

are mockernut hickory (Carya tomentosa Nutt.) and pignut hickory (C. glabra (Mill.) Sweet). It seems likely that shortleaf pine (Pinus echinata Mill.) holds a place in the climax on the drier ridges and south slopes. The original General Land Office survey notes for the forest list 16 per cent of the witness trees as pines. These were probably in the main shortleaf pines on dry sites, with occasional loblolly pines (P. taeda L.) along streams.

Succession on old fields seems to follow essentially the pattern observed by Oosting (1942) for the Piedmont region of North Carolina. Herb and grass stages are quickly followed by a pine stage. Hardwoods appear under the pines normally after they are 30 or 40 years old, but may appear much earlier or much later than this. The principal hardwood species at this time are sweetgum (Liquidambar styraciflua L.), blackgum (Nyssa sylvatica Marsh.), and common persimmon (Diospyros virginiana L.), but the oaks, hickories, flowering dogwood (Cornus florida L.), and red maple (Acer rubrum L.) make their appearance and increase slowly but steadily. With undisturbed succession, the forest should be close to climax after 200 years. It will very likely have lost its "pure pine" status after 100 years as the understory hardwoods begin to come up into openings in the pine canopy.

Other successional series are instituted by fires, but these are not so well understood. The most obvious primary invaders following fire are the sumacs (Rhus glabra L. and R. copallina L.), the briars (Rubus spp.), vines (Smilax spp., Vitis spp., and Lonicera japonica Thunb.), and in good seed years, shortleaf and loblolly pines.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that proper record-keeping is essential for transparency and accountability, particularly in financial matters. The text suggests that organizations should implement robust systems to track and document every aspect of their operations, from procurement to sales.

2. The second part of the document addresses the challenges of data management in a rapidly changing environment. It highlights the need for flexible and scalable solutions that can adapt to evolving requirements. The author argues that investing in modern data infrastructure is crucial for ensuring long-term success and competitiveness.

3. The third part of the document focuses on the role of technology in enhancing operational efficiency. It explores various digital tools and platforms that can streamline processes and reduce manual errors. The text encourages organizations to embrace innovation and leverage technology to optimize their workflows and improve overall performance.

4. The fourth part of the document discusses the importance of collaboration and communication in achieving organizational goals. It stresses that effective teamwork and clear communication are fundamental for success. The author suggests that organizations should foster a culture of openness and collaboration, where team members are encouraged to share ideas and work together to solve problems.

5. The fifth part of the document addresses the issue of risk management and compliance. It emphasizes that organizations must proactively identify and mitigate potential risks to avoid legal and financial consequences. The text provides guidance on developing comprehensive risk management frameworks and ensuring adherence to relevant regulations and standards.

6. The sixth part of the document discusses the importance of continuous learning and development. It argues that organizations should invest in training and development programs to keep their workforce up-to-date with the latest skills and knowledge. The author suggests that a commitment to learning is essential for staying ahead in a competitive market.

7. The seventh part of the document focuses on the importance of customer satisfaction and loyalty. It emphasizes that providing excellent customer service is a key differentiator for organizations. The text suggests that organizations should implement strategies to understand customer needs and preferences, and tailor their offerings accordingly to ensure high levels of satisfaction and loyalty.

8. The eighth part of the document discusses the importance of sustainability and social responsibility. It argues that organizations have a responsibility to contribute positively to society and the environment. The text suggests that organizations should adopt sustainable practices and engage in social responsibility initiatives to enhance their reputation and long-term viability.

9. The ninth part of the document addresses the importance of innovation and research and development. It emphasizes that organizations must invest in R&D to drive innovation and create new products and services. The author suggests that organizations should foster a culture of innovation and encourage employees to think creatively and explore new possibilities.

10. The tenth part of the document discusses the importance of strategic planning and vision. It emphasizes that organizations need a clear vision and strategic plan to guide their actions and achieve their long-term goals. The text suggests that organizations should regularly review and update their strategies to remain relevant and competitive in a dynamic market.

Current Forest and Soil Conditions in
the Light of Past Land Use

The Fayette Experiment Forest is composed of ten ex-family farm units. The cash crop on these farms was cotton. Due to the boll weevil, soil depletion, and changing economic conditions, cultivation was discontinued on most of the units between 20 and 50 years ago. It was discontinued on two of the units in 1944 and 1949 respectively.

Approximately 44 per cent of the Forest area has been cleared and cultivated in the past. Some erosion occurred on nearly all the sloping areas, but it was particularly severe on the Atwood and the Boswell soils. These soils were apparently the most fertile and were therefore the most persistently abused, with the result that both sheet and gully erosion were intensive. Most of this is now stabilized under a forest cover, but the gullies are still evident, and the soil profiles are often more or less truncated with the result that compact and heavy-textured subsoils are often at or near the surface.

Succession on the old fields has followed the normal sequence except as modified by wildfires previous to 1945. The rate of succession has been abnormally slow on areas without topsoil, and some of these are still not completely out of the grass stage. The proportion of old field area now in naturally reseeded pine is 86.5 per cent, 38 per cent of the Forest area or 520 acres. Most of the remaining 75 acres of old field has been planted to pine. The natural pine stands vary in age from approximately 15 to 40 years with a majority of them being between 25 and 35 years. Stocking varies from open and patchy to dense and closed. Undergrowth may be absent,

predominantly grass, predominantly vines, predominantly reseeding pines, or predominantly hardwoods. Hardwood undergrowth is more or less apparent in most of the pine stands, conspicuous in some of them, but is often absent because of severe past erosion, dense pine overstory, dense growth of vines, or recentness of cultivation.

Figure 2 shows forest cover types and age classes in the Fayette Experiment Forest. Formerly cultivated areas are all in pine types or are open. Uncultivated areas are in pine-hardwood and in hardwood types. The cover type names and numbers are in accordance with the Society of American Foresters' "Forest Cover Types of the Eastern United States" (1932).

The forest humus types fit better into the classification of Hoover and Lunt (1952) than into that of Heiberg and Chandler (1941). The driest pine ridges and slopes commonly produce an "imperfect mor" with no H layer and no A_1 horizon. Dry-site oak and pine-oak stands normally produce a "thin mor" humus type; occasionally they produce the closely related "thin shallow duff mull". Many of the moister site pine areas exhibit a "shallow sand mull" humus type which differs from the imperfect mor in having a modest A_1 development. Moist hardwood and pine-hardwood sites commonly produce a "shallow coarse mull" or "shallow medium mull" humus type.

The Forest was extensively culled over for pine sawtimber for 25 years previous to 1945. Fires were frequent and destructive during this time. The last extensive wildfire, around 1941, preceded a bumper pine seed crop and was followed by the last widespread regeneration of loblolly and shortleaf pine on the Forest.

PROCEDURE

Experimental Design

The experimental design was a randomized block, split plot structure with main burning treatments applied to two topographic positions and with superimposed subtreatments of hardwood poisoning. Each of the 6 blocks contained 6 plots, one for each main treatment on each topographic position as follows:

RA -- ridge, August burned

SA -- slope, August burned

RJ -- ridge, January burned

SJ -- slope, January burned

RO -- ridge, not burned

SO -- slope, not burned

Each rectangular 2-acre plot was divided into two square 1-acre subplots. On one of these, all hardwoods 4 inches and over in diameter breast high were killed by poisoning (P); on the other, no poisoning (O) was done. Each subplot was designated by a number and letters to indicate its block location and its treatments; thus subplot 6SOO was in block 6, had a slope-non-burn main treatment, and had a non-poison subtreatment.

Each 1-acre subplot was 3.162 chains square. The actual sampling area inside of this was 1/2 acre in size and 2.236 chains square, leaving an isolation strip .688 chain or 45.4 feet wide. In the center

of each subplot was a circular .01-acre plot, 11.8 feet in radius, designated as a reproduction plot. The area surrounding the reproduction plot, out to 16 feet in radius, was designated as the soil and litter sampling area.

Location of Plots

The plot locations are shown on Figure 1. Only three factors controlled the plot locations within the forest: (1) they had to lie within short walking distances of driveable truck trails; (2) they had to be located in natural pine types; and (3) there had to be 3 ridge plots and 3 slope plots for each block. The blocks were more or less fortuitous and were not geographically segregated in every case (Figure 1). Treatments within blocks and topographic categories were of course assigned at random. The ridge plots were actually located on ridges and upper slopes; the slope plots were located on middle and lower slopes.

The variation within treatments in soil, in humus types, in topography, in pine stocking, in hardwood stocking and composition, and in the composition of lesser vegetation was enormous. The variation in soil properties alone was sufficient to indicate that this experiment was exploratory in nature, as indeed it was intended to be.

Application of Treatments

Burning

August burning was applied in 1951 and in 1954; January burning was applied in 1952 and in 1955. The prescribed conditions for burning were as follows.

For August burning:

1. No rain for 3 to 5 days.
2. Fire danger class 3, or maybe 4 (Jemison et al., 1949).
3. Calm or light air (wind not over 3 miles per hour).
4. Air temperature above 75° F.
5. Relative humidity less than 75 per cent.
6. Fires to be set against the wind if possible.
7. Fires on slopes to be set to burn downhill.
8. Desired burning conditions expected between 1 p.m.
and 4 p.m.

For January burning:

1. No rain for 3 days.
2. Fire danger class 3, or maybe 4.
3. Wind not over a gentle breeze (Beaufort scale No. 3;
less than 12 miles per hour).
4. Air temperature 40° F. or above.
5. Relative humidity less than 75 per cent.
6. Fires to be set against the wind regardless of slope.
7. Desired burning conditions expected between 11 a.m.
and 3 p.m.

It was suggested by the writer in 1953 that the rainfall and relative humidity conditions above were entirely too broad, since they allowed a considerable moisture content variation in both heavy and light fuels. For the 1954 August burns therefore, it was stipulated that the rainfall occurring 3 to 5 days previous to burning should be at least .5 inch, and that the moisture content of fuel moisture sticks

(Jemison et al., 1949) should be less than 5 per cent. For the 1955 January burns the .5-inch minimum rainfall was again stipulated, but fuel moisture content of sticks was set at 5 to 10 per cent.

During the 1951-52 burns, there was no rain guage and no fire weather station at the Forest. Rainfall was measured at the city of Fayette, ten miles south, and fire danger classes had to be estimated. The fuel accumulations were generally heavy, for it had been 10 years since the latest wildfire had burned over most of the area.

The 1951 August burnings were done under the following conditions:

Days after a substantial rain 3 to 8

Danger class (estimated). 3

(2 for plot 3RA)

Wind velocity 2 to 5 m.p.h.

Air temperature 88° to 98° F.

Relative humidity 50% to 70%

(30% to 50% for plots 3SA and 5SA)

Time of day 12:30 to 5:00
p.m.

The fires were exceedingly hot in many places and on 4 of the 12 plots, 1RA, 6RA, 3SA, and 6SA, pines up to pole sizes were killed outright. While all hardwoods 3 inches d.b.h. and smaller were killed to the ground on these 4 plots, such was not the case on the other 8 plots. The proportions by d.b.h. classes of the small gums, oaks, hickories, and dogwoods killed on the 12 plots were as follows:

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1 inch	62 per cent
2 inches	52 per cent
3 inches	38 per cent

Thus it is obvious that there must have been considerable variation overall in the heat of burning. The writer was not present for these burns, not having come upon the scene until 1953, but since weather conditions were satisfactory for burning and fuel amounts must have been ample even under open canopies, he feels that fuel type must have had a predominating influence. It is noteworthy that on some of the plots which sustained the least kill of small hardwoods, thickets of hardwood saplings and poles under very light pine canopies were common. The extent of destruction of the forest floor is not known, but fresh litter from scorched trees and from normal autumn leaf cast must have soon fallen and reinforced the residual floors.

The 1952 January burnings were done under the following conditions:

Days after a substantial rain	9 to 12
(not known for 1RJ and 1SJ--more than 6)	
Danger class (estimated).	3 to 4
Wind velocity	0 to 8 m.p.h.
Air temperature	58° to 69° F.
(76° to 80° F. for 1RJ and 1SJ)	
Relative humidity	25% to 70%

Time of day 9:45 a.m. to 5:45 p.m.

Except on plots 1RJ and 1SJ, these fires burned much more slowly than did the August fires and must have been considerably less hot. The only tree over 2 inches d.b.h. recorded as killed to the ground was a 3-inch sassafras (Sassafras albidum (Nutt.) Nees) on plot 6RJ. On only 1 plot, 1RJ, were all of the 1-inch trees killed. The proportions by d.b.h. classes of the small gums, oaks, hickories, and dogwoods killed on the 12 plots were as follows:

1 inch	46 per cent
2 inches	5 per cent
3 inches	0 per cent

The greatest difficulty in burning seems to have been encountered on north slopes and where the ratio of hardwood litter to pine litter was high. The degree of destruction to the forest floor is unknown but must have been slight in some places. It may have been complete for pine litter on south slopes because of the long drying periods before fires.

The 1954 August burnings were done under the following conditions:

Amount of preceding rainfall (August 16 to August 21) . . 2.20 in.
Days between rain and burning 2 to 6
Danger class 3 to 4
Wind velocity 1.5 to 7.5 m.p.h.
Air temperature. 90° to 100° F.

Relative humidity 35% to 54%

Moisture content of fuel moisture sticks. . 3.5% to 6.0%

Time of Day. 12:30 to 5:45 p.m.

The fires were much slower than they had been in August, 1951⁸. Mr. Frank Smith, who supervised all the burnings, observed that the severity of all the 1954 fires was mild in comparison with the 1951 fires. Since the weather conditions appear to have been just as conducive to hot burning as they had been in 1951, the difference in burning severity must be ascribed to a difference in fuel accumulation at the two times (See data and discussion on weights and depths of forest floor). No trees above 3 inches d.b.h. were killed outright. The proportions by d.b.h. classes of the small gums, oaks, hickories, and dogwood killed were lower than in 1951 and were as follows:

1 inch	49 per cent
2 inches	44 per cent
3 inches	17 per cent

The greatest difficulty in burning was encountered in areas where the forest floor was very thin and in areas where hardwood litter predominated and pine litter was sparse or missing.

The writer observed the 1954 August burnings and was surprised at their "tameless". Flames were usually from 6 inches to 2 feet high, and the backfires moved very slowly. Half of the 24 .01-acre center

⁸ Plot 4SA burned in 1 hour, 50 minutes in 1951; the 1954 burn took 4 hours, 30 minutes. Plot 5RA burned in 55 minutes in 1951; it burned in 1 hour, 45 minutes in 1954. Comparisons are similar for all plots.

plots involved did not burn over completely, 6 plots burned less than 90 per cent, and 2 plots burned 50 per cent or less. The forest floor was rarely completely destroyed even when less than 1/2 inch thick before burning. However the residual floor after burning was often so thin that it would have afforded little protection to the soil from an intensive rainfall. Fortunately only one storm of note occurred during the succeeding month, a rainfall of 1.24 inches on September 21. Reactions to this storm were not observed.

Notes on fuel types and their reactions during the 1954 August burnings are included in the Appendix.

The 1955 January burnings were done under the following conditions:

Amount of preceding rainfall (January 22).62 inch

Amount of preceding rainfall (on February 6

for plots 4SJ and 5SJ) 3.19 inches

Days between rain and burning 3 to 9

Danger class. 2 to 3

Wind velocity 2.0 to 7.5 m.p.h.

Air temperature 45° to 64° F.

Relative humidity 33% to 48%

(for plots 4SJ and 5SJ) 56% to 73%

Moisture content of fuel moisture sticks. . 5.0% to 9.0%

(for plots 4SJ and 5SJ) 8.6% to 10.5%

Time of day 11:00 a.m. to 5:40 p.m.

The fires burned at about the same rates as had the 1952 January burns. They burned a little more briskly than the 1954 August fires

had burned, even though previous to the August burns litter accumulation was no greater on the January plots than on the August plots. The reason for the relatively good 1955 January burns is of course the fresh fuel added to the forest floor during normal leaf fall in the previous autumn. Also, herbaceous vegetation was in a cured condition rather than in a green condition as it had been for the August fires. In spite of these factors however, the 1955 January burns had less killing effect than had the previous August fires⁹. The proportions by d.b.h. classes of small gums, oaks, hickories, and dogwoods killed to the ground were as follows:

1 inch	18 per cent
2 inches	6 per cent
3 inches	0 per cent

The greatest burning difficulty was encountered on north slopes and in hardwood thickets where the pine overstory was open. The residual forest floor was generally good and averaged nearly 1/2 inch in thickness.

Poisoning

On the subplots designated for hardwood poisoning, all small and undesirable hardwood trees 4 inches d.b.h. and over were poisoned with ammonium sulfamate (Ammate) between March 1 and May 9, 1952. Ammate crystals were placed in chopped cups around the root

⁹The importance of air temperature on the killing effect of fire was brought out by Nelson (1952) who observed that a tree crown on a cold day at 40° F. requires about two and one-half times as much heat to reach a lethal temperature as does a crown on a hot sunny day at 100° F.

collars of the trees according to the method outlined by Peavy and Campbell (1949). Liberal dosages were used, particularly on hickories and white oaks, since the intent was to kill the trees rather than to test the poison. On the 36 half-acre subplots involved, 549 hardwoods were poisoned as being culls or undesirable; no more than a dozen or so were left as being desirable.

The hardwood poisoning and kill in number of trees per acre varied from zero to 142; in basal area per acre it varied from zero to 27.84 square feet. The mean values were 30.5 trees and 6.23 square feet per acre. The overall treatment intensity then amounted to the poisoning and killing of one 6-inch hardwood at each 37.8-foot interval on the ground. The treatment therefore was a very light treatment.

Collection of Field Data and Samples

Measurements and Samples of the Forest Floor and of the Soil

For the purpose of obtaining measurements and samples of the forest floor and of the soil, four stations were used within each of the 72 subplots. For the first set of measurements and samples, these stations were located 15 feet out from the subplot center stake in the four cardinal directions. Starting with the north station and going clockwise, the stations were numbered from 1 to 4. For subsequent samplings and measurements, each station was moved in a clockwise direction about the center stake, maintaining the 15-foot radius, to the extent necessary for locating undisturbed

ground. Whenever a station fell at a tree, on an undecomposed log, or on a large rock, it was rotated far enough for avoidance of the obstacle. Occasionally stations were also moved in order to avoid such unusual and comparatively rare features as obvious old roadbeds, artificial ditches, etc. Stations were not moved to avoid gullies and other erosion features, nor to avoid decayed logs which had become part of the F and H layers of the forest floor.

Forest floor and soil samples were taken between December 19, 1953, and February 20, 1954 (previous to the 1954-55 burnings), and between February 15 and April 15, 1955 (subsequent to the 1954-55 burnings). The second set of samples from 22 of the 24 January-burn subplots was taken on March 17, 1955, from 6 to 7 weeks after the plots were burned. Rainfall during this period was approximately 8 inches.

Sampling and measuring the forest floor

Forest floor samples were exactly 1 foot square and were taken to the mineral soil. A 1-foot square piece of 5-ply plywood was placed on the forest floor and held firmly in place by means of a 1-inch by 1/2-inch handle. The sample was then cut by means of running a freshly filed machete around the edges of the board into the mineral soil (Figure 3). With the board still held in place, the surrounding forest floor was raked away from the board for a distance of 6 inches around it. The mean thickness of L, F, and H layers was then found by measuring these at the midpoint of each side of the board (Figure 4). While these measurements were being taken, the board was pressed gently



Fig. 3.--Cutting the forest floor sample. The plywoodboard is 1 foot square.



Fig. 4.--Measuring L, F, and H layers after surrounding forest floor has been raked back.

from above to the extent necessary for removing any "fluffiness" of the litter. After measurements, the board was removed (Figure 5) and the forest floor sample carefully placed in a sack marked with the subplot number and the station number. Great care was taken in attempting to get all of the sample into the sack without including any mineral soil (Figure 6), but in spite of this, considerable mineral soil was often included.

Sampling the soil

After forest floor sampling, an undisturbed soil sample of the top 3 inches of mineral soil was obtained from each station using the method of Uhland and O'Neal (1951). This method makes use of the Uhland volumetric sampler which extracts undisturbed soil samples in aluminum cylinders 3 inches long and 3 inches in diameter (Figures 7 and 8). Each sample was taken as closely as possible to the exact center of the forest floor sampling area. The sample was rough-trimmed at each end of the cylinder, and the cylinder with its soil was then placed in a cylindrical ice cream box for transportation to the laboratory.

A pint composite sample of the top 3 inches of mineral soil was obtained from each subplot. Approximately a quarter of this sample was obtained from each station after the undisturbed sample had been removed. The sample was obtained by means of repeatedly thrusting a 1-inch sampler tube 3 inches into the soil (Figure 9). Five or six thrusts per station would give approximately a quarter-pint of soil, and these thrusts were scattered about the 1-foot square area from



Fig. 5.-The plyboard removed and the forest floor sample ready to be picked up.



Fig. 6.-Sweeping up the last bit of duff.



Fig. 7.-The Uhland volumetric sampler ready for driving into soil.



Fig. 8.-Rough-trimming the base of the volumetric sample with a hunting knife. Cylinder and sample fit snugly into the ice cream container.

which the forest floor sample had been taken.

The soil profile was described at station 1 on each subplot. On two subplots within each soil type, samples were collected from each soil horizon.

Measuring infiltration rates

Field infiltration rates were measured between January 14 and June 27, 1955, subsequent to the last January burns. Six of the January-burn subplots were measured only 4 weeks after being burned, but 6 inches of rainfall had fallen on them during that time nevertheless. The other 18 January-burn subplots were measured after April 1, and all had received at least 10 inches of rainfall subsequent to burning.

The method used was that described by Lutz (1940). After removing the L layer of the forest floor, a steel cylinder, 20 centimeters high and having an inside cross-sectional area of 100 square centimeters, was driven sharpened end down 10 centimeters into the soil (Figure 10). A piece of muslin was then placed inside the cylinder for the purpose of breaking water impact on the soil, and a half-liter of water was added (Figure 11). Time was recorded in seconds from the first impact of the water on the muslin until the water disappeared into the soil.

Infiltration rates were measured only when the topsoil was at or very near field capacity. Eight measurements were made on each subplot, two at each station with the individuals of the pair spaced 2 feet apart.



Fig. 9.-Thrusting 1-inch sampler tube 3 inches into topsoil to obtain portion of composite sample.



Fig. 10.-Driving infiltration tube into topsoil.

The obtaining of valid measurements from the Boswell soils and from the rockier Gilead soils proved to be extremely difficult. It was sometimes necessary to move about so radically in order to get the cylinder into the ground that representative sampling became a doubtful issue. Similar troubles with the smaller and more efficiently driven Uhland volumetric sampler were much less onerous.

Cover of Lesser Vegetation

The cover of lesser vegetation was measured during June, 1954. This was previous to the 1954-55 burnings, so only the effects of the 1951-52 burnings were measured. However, Moore (1956) measured vegetative cover in all of the nonpoisoned subplots during the late spring of 1955 subsequent to the 1954-55 burnings.

The method used was the line interception method as outlined by Canfield (1941). From a point 7 feet east of the subplot center stake, 25 feet of line intercept was laid out north and 25 feet south. This process was repeated from 7 feet west of the center stake. The total amount of line intercept per subplot was therefore 100 feet. Vegetation no more than 6 feet above the ground was measured to the nearest .01 foot where intercepting a vertical plane projected from a taut wire along the forest floor. All parts of woody vegetation intercepted were measured, but herbaceous vegetation was measured only where emerging at the ground line. The number of strata recognized up to 6 feet above ground at individual points along the line was variable, usually 2 or less, rarely more than 3, depending on the number of plant species involved at the time. These strata were not

tallied separately.

Forb and shrub species were identified from Fernald (1950); occasional species not found in Fernald were identified from Small (1933). Hitchcock (1935) was used in identifying grass species. All names were cross-checked in "Standardized Plant Names" (Kelsey and Dayton, 1942).

All intercepting tree vegetation more than 6 feet above the ground was tallied in 3 broad canopy classes designated as sapling canopy, pole canopy, and timber canopy. Species were not tallied separately, but the principal species occurring within any one stretch of canopy were always listed.

In the spring 1955 study conducted by Moore (1956), a 50-foot line intercept was located at random in each non-poisoned subplot. All intercepting vegetation was tallied. Two strata were recognized, these being a grass-forb stratum and an overstory stratum.

Growth Response of Pines

Although long-term studies on the growth response of pine timber to burning and hardwood poisoning have been continuously in effect on the plots since their inception, the writer attempted nevertheless to obtain short-term growth responses through the use of a dial gauge micro-dendrometer (Figure 12). The basic instrument and growth measurement technique were developed by Daubenmire (1945) and used by Holsoe (1951). The dendrometer used in this study was a steel platform type manufactured by the B. C. Ames Company of Waltham, Massachusetts. It was capable of measuring changes in tree radius of .001



Fig. 11.-Pouring water into infiltration tube and measuring time of infiltration.



Fig. 12.-Using a dial gauge micro-dendrometer to measure radial growth of a loblolly pine.

inch; by interpolation, a rough approximation could be made to the nearest .0001 inch.

In each subplot 3 pines 5 inches and over in d.b.h. were located at random for growth study. Dendrometer stations were installed on the north sides of each of these 216 trees. Readings were taken on all trees at weekly and bi-weekly intervals from July 16 to October 8, 1954, and at bi-weekly and monthly intervals from March 12 to November 5, 1955. The readings were always taken in the same order so that each tree would always be measured at approximately the same time of day. To control some of the fluctuations in readings due to changes in the temperature and humidity of the air, tree readings were always corrected for fluctuations in "dead readings" taken on a heavy piece of timber hung outdoors under a pine. Readings on the "dead station" were always taken just before and just after complete sets of readings on the live trees.

Laboratory Analyses of Samples

Forest Floor Samples

After being air dried, forest floor samples were treated for extraction of mineral matter. The method consisted of dumping the sample onto a 3/4-millimeter screen, picking off the coarser organic matter by hand, picking out any rocks and pebbles by hand, and sieving the remaining mineral matter through the holes, macerating mineral aggregates with the fingers when necessary. The method was not completely accurate, but it was infinitely superior to no treatment at all. Both mineral and organic portions of the forest floor sample

were then oven-dried for 24 hours at 105° C. and weighed.

The cleaned forest floor sample was then ground in a Wiley mill to go through a 1-millimeter screen. The 4 ground samples from each subplot were thoroughly mixed to form a composite sample. Duplicate subsamples were then extracted from the composite sample, placed in glass jars, oven-dried for 24 hours at 105° C., and the glass jars were then tightly capped. These duplicate subsamples were used subsequently for chemical analyses.

Total nitrogen per cent in each forest floor subsample was determined by the semi-micro Kjeldahl method as outlined by Hagler (1953). The method consisted essentially of an adaptation of Ranker's (1927) modification of the salicylic-thiosulfate method to the Kemmerer-Hallett (1927) distillation apparatus.

For further chemical analyses of the forest floor, it was necessary to prepare an ash solution from each subsample. This was done with 2-gram sub-subsamples using the dry-ashing procedure given by Piper (1950). Each ash solution was brought to 100 cubic centimeters volume and stored for subsequent analyses.

Calcium and potassium concentrations were determined by burning the ash solutions in a Beckman model DU flame photometer and comparing light intensities at specified wave lengths with intensities from standard solutions.

Phosphorous in the ash solutions was determined according to the method of the Association of Official Agricultural Chemists (1945). Light transmissions were determined with a Coleman colorimeter having a 640 mu. filter inserted, and were compared with transmissions of

standard solutions.

Composite Soil Samples

Twenty-four of the 72 composite topsoil samples taken during the winter of 1953-54 were selected at random and tested for particle density with the method given by Emerson (1925). The mean particle density was 2.595 with a standard deviation of $\pm .034$. This mean value was subsequently used in porosity calculations.

After being air-dried, the composite samples were screened in a 2-millimeter sieve and the two fractions weighed. The material less than 2 mm. in size was used for mechanical analysis and for chemical analyses. All analyses were made in duplicate.

Mechanical analysis was done according to the method of Bouyoucos (1936). No change in mechanical analysis was expected as the result of burning or poisoning, so only one complete set of samples, the 1955 set, was analyzed.¹⁰ Hydrometer readings at 40 seconds were used to separate out the sand fractions, and readings at 2 hours were used to separate silt from clay.

pH's were measured on a Coleman pH meter according to the general method of Piper (1950) and the specific directions of Russel (1950). The ratio of soil to water used in the testing mixture was 1 to 2.5.

Soil organic matter was determined by the wet combustion method as outlined by Peech et al. (1947). This method consists basically of oxidizing carbon in the soil with potassium dichromate and titrating

¹⁰The purpose of mechanical analysis in this case was the possible use of the results in covariance.

the excess by reducing with ferrous sulfate. Per cent carbon must then be converted to per cent organic matter by multiplying by the conventional 1.724.

Total nitrogen in the soil was determined by the Kjeldahl method as given by the Association of Official Agricultural Chemists (1945).

For the determination of available calcium and potassium, 10-gram subsamples were each leached with 250 milliliters of ammonium acetate. These solutions were burned on the flame photometer and the light intensities at specified wave lengths compared with intensities from standard solutions.

Soil phosphorous was determined by means of weak acid extraction according to the Truog (1930) method. However, instead of using a ratio of soil to extracting solution of 1 to 200, as specified by Truog for obtaining approximately available phosphorous, it was necessary in this study to use a ratio of 12 to 200. Filtered solutions from the lower ratio extractions barely developed color, and the transmission readings on the Coleman colorimeter were mostly over 96 per cent. It was necessary to develop higher color intensities in order to obtain some degree of sensitivity when comparing treatments. The higher ratio of soil to extracting solution developed color intensities that gave transmissions from 83 to 98 per cent, corresponding to .16 to .025 p.p.m. of phosphorous in solution. Soil concentrations calculated after using the higher ratio of soil to extracting solution were only 22 to 40 per cent as high as they would have been had the lower ratio been used.

Undisturbed Soil Samples

Each volumetric soil sample was carefully trimmed at each end of the 3-inch by 3-inch aluminum cylinder until the soil was exactly flush with the cylinder ends. A piece of paper toweling was then placed over the bottom end and held with a strong rubber band. The samples were weighed and then saturated by standing them in 2-1/2 inches of water for at least 24 hours. They were then placed on tension tables and left under 60 centimeters tension for 24 hours. Immediately upon removal from the tension table, the samples were again weighed and placed in an oven to dry at 105° C. for 24 hours. Upon removal from the oven, they were weighed for the last time.

The basic design for the tension tables was that of Leamer and Shaw (1941). The tables used were of the asbestos type and had been built by Jamison and Reed (1949) for the U. S. Department of Agriculture Tillage Laboratory at the Alabama Polytechnic Institute.

The procedure outlined enabled the calculation for each sample of field moisture per cent, bulk density, total porosity, macroporosity, and microporosity. The proportion of the soil volume occupied by pores drained at 60 centimeters of tension has been termed macroporosity; the value is very close to non-capillary porosity and to air capacity. The proportion of the soil volume occupied by pores not drained at 60 centimeters tension has been termed microporosity; this value is very close to capillary porosity and to field capacity (volumetric basis).

A sample form used for recording and calculations of volumetric data is shown in Table 4.

TABLE 4.--Sample form showing data from undisturbed soil samples from one subplot

Physical Data from Volumetric Soil
Samples Taken During Winter 1953-54

Samples taken by E.J.H.

Date 1-3-54

Subplot No. 1RAP

Lab. Analysis by E.J.H.

Date 1-16-54

	Samples				Ave.
	No. 1	No. 2	No. 3	No. 4	
1. Cylinder No. ^a	48	45	49	43	
2. Wt. of Soil $\pm$ Cyl. ^a - gms.	578	568	597	592	
3. Wt. of Soil $\pm$ Cyl. ^a at 60 cm. Tension - gms.	595	591	622	613	
4. Wt. of Soil $\pm$ Cyl. ^a oven-dry - gms.	541	542	566	562	
5. Wt. of Cyl. ^a - gms.	163.3	163.3	163.3	163.3	
6. Wt. of Oven-dry Soil - gms.	377.7	378.7	402.7	398.7	
7. Field Moisture - % wt.	9.8	6.9	7.7	7.5	8.0
8. Volume Weight	1.088	1.091	1.161	1.149	1.122
9. Particle Density	2.595	2.595	2.595	2.595	
10. Total Porosity - % vol.	58.1	58.0	55.3	55.7	56.8
11. Pores Not Drained at 60 cm. Tension - ml.	54	49	56	51	52.5
12. Pores Not Drained at 60 cm. Tension - % vol.	15.6	14.1	16.1	14.7	15.1
13. Air Capacity at 60 cm. Tension - % vol.	42.5	43.9	39.2	41.0	41.7

^aWeight of cylinder includes weight of paper toweling and rubber band.

RESULTS AND DISCUSSION

Data taken in 1955, after both series of burnings, were subjected to analyses of variance (Snedecor, 1946) in order to determine the significance of the accumulative changes following all treatments.

These first analyses, particularly the ones involving properties of the mineral soil, frequently produced significant interactions of both the first and the second order. The principal cause of these interactions was pinpointed to a lack of representative distribution of all treatment classes with reference to pre-treatment soil properties. It was found in particular that the SJ plots had suffered more past erosion than any other comparable treatment group, and that within this group the non-poisoned subplots had apparently eroded more in the past than had the poisoned subplots. These facts alone were sufficient to cause significant second order interactions.

Through the use of numerous scatter diagrams and trial covariance analyses¹¹, a covariant was sought from among the data available that would adequately reflect differences in past erosion and permit adjustment of treatment means for this factor. The best of the several possibilities turned out to be the per cent of silt plus clay in the topsoil. The type of relationship involved between this covariant

¹¹Covariance analyses followed the method of Federer (1955). See Appendix B for examples of statistical procedures.

and the various other properties of the mineral topsoil is illustrated by a scatter diagram of mean subplot potassium values plotted over silt plus clay means (Figure 13). In addition to reflecting the past removal of light-textured topsoils through erosion, the silt plus clay factor may also have reflected to some extent original differences in soil types.

After the 1955 data were analyzed, the 1953-54 and the 1955 data were subjected to combined analyses of variance in order to determine the significance of changes following the second series of burnings alone. These were sensitive tests, involving as they did both pre-treatment and post-treatment sampling. Residual fire effects between these analyses and the analyses of the 1955 data alone were assigned to the first series of burnings.

The Forest Floor

The forest floor samples as taken from the field contained an average of approximately 25 per cent by weight (oven-dry basis) of mineral matter. Based on the mean values for the 72 subplots, the relationship between the cleaned sample and the field sample was:

$$Y = 0.743X - 1.5^{12}$$

where Y = oven-dry weight of the cleaned sample in grams per square foot, and X = oven-dry weight of the field sample in the same units. Using the same technique with chaparral litter, Kittredge (1955) obtained a relationship of $Y = 0.5X + 0.5$.

¹²r = .926, standard error of estimate = $\pm$ 25 per cent.

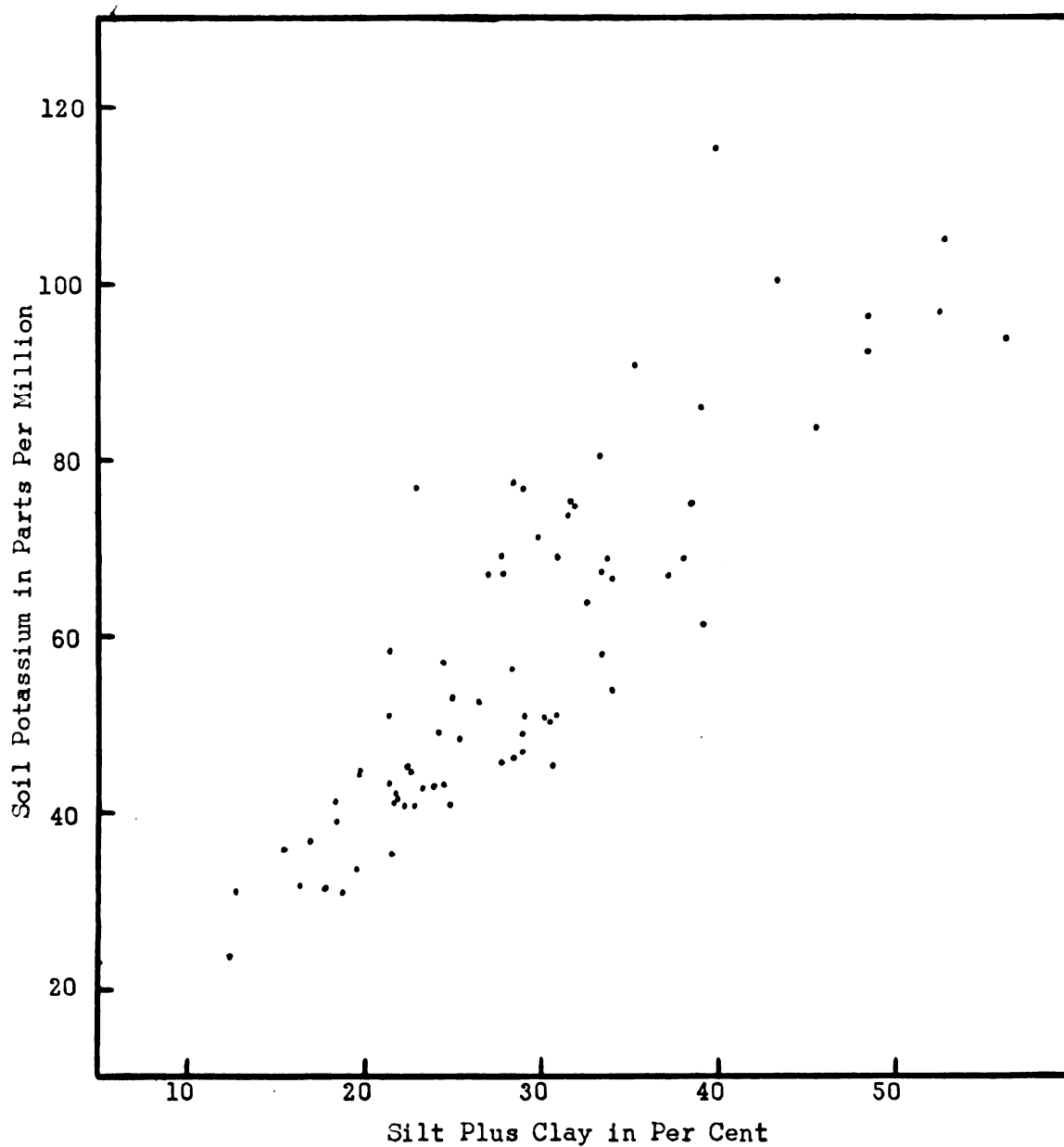


Fig. 13.-A scatter diagram showing the close relationship between available potassium and texture in the top 3 inches of mineral soil. Each point represents one subplot.

Weight and Depth of the Forest Floor

The mean weights and depths of the forest floor from the 1955 measurements are given by treatment classes in Table 5. The total

TABLE 5.--Weights and depths of the forest floor from the 1955 measurements

Treatment	Pounds per Acre ^a		Inches Depth	
	Mean	L.S.D. ^b	Mean	L.S.D. ^b
Ridge	8653	2295	.574	.128
Slope	7635		.556	
August burn	5282		.349	
January burn	7702	2814	.483	.157
Check	11447	1344	.864	.095
Poisoned	8163		.576	
Check	8124		.554	

^aOven-dry basis.

^bLeast significant difference (5 per cent level).

variation in forest floor weights among the 72 subplots was from 384 pounds to 25,929 pounds per acre.

The difference between the non-burned plots and the burned plots, on both the weight basis and the depth basis, was highly

significant¹³. The superiority of the January burned plots in both weight and depth of forest floor over the August burned plots barely missed significance at the 5 per cent level. However, at least half of the forest floor of the August burned plots consisted of litter fallen subsequent to treatment; the January burned plots contained no fresh litter. It can be safely concluded that the August burnings left a significantly lighter and thinner forest floor than did the January burnings. Conservatively speaking, the August burnings could have left no more than an average of 3000 pounds per acre or .2 inch thickness of forest floor. This was a dangerously small amount, but fortunately there was only mild rainfall in the interval before fresh litter fell to the ground.

There was apparently no effect of topography or of the light hardwood poisoning treatments on the amount of forest floor.

In the analyses combining the 1953-54 data with the 1955 data, the combined fire effect and the years effect¹⁴ were highly significant, but fire X years was not significant for either weights or depths of the forest floor. In view of the high sensitivity of the combined analyses, this is taken to mean that the differences in forest floor measured in 1955 were due primarily to the first fire treatments, the August 1951 and the January 1952 burnings. To

¹³In this paper, the term "highly significant" refers to significance at the one per cent level. The term "significant" refers to significance at the 5 per cent level, but failing to attain the one per cent level.

¹⁴The amount of forest floor on non-burned plots was greater in 1953-54 than in 1955. This may have been due to differences in field or laboratory techniques.

assume however that the August 1954 and the January 1955 burnings caused no loss of the forest floor is ridiculous; the loss was simply too small to indicate a significant change at the 5 per cent level.

By way of verification, analysis of variance of the 1953-54 data alone for forest floor depths gave a highly significant superiority of non-burned plots over burned ones. The superiority of January burned plots over the August burned plots was not quite significant, but allowance for the extra year of litter fall on the August plots easily made the difference significant. The forest floor depths by burning treatments in 1953-54 were:

August burned	.746 inch
January burned	.888 inch
Check	1.118 inches

The least significant difference was .230 inch.

Adjusting the 1953-54 forest floor depths to 1955 conditions on the basis of the change in depth for the check plots, one obtains:

August burned	.492 inch
January burned	.634 inch
Check	.864 inch

In terms of 1955 data, the mean forest floor depth of the August plots just before the August 1954 burnings could have been no more than indicated here, for between the winter measurements and the summer burning, decomposition rate will have been at least equal to litter fall. Forest floor depth on the January plots just before burning in 1955 must have been approximately the same as indicated

here, for during the year between measurements and burning, decomposition and litter fall must have been approximately equal.

From all this, one might extract a .5-inch forest floor depth as a key figure. A forest floor of this depth is insufficient for producing a hardwood-killing fire¹⁵ and at the same time leaving adequate protection for the soil. Also, it can be said that a forest floor under .5 inch thick constitutes no high fire hazard. These conclusions can be applied only in a very broad manner since the data on which they are based came from a great variety of field conditions.

Chemical Properties of the Forest Floor

Nutrient concentrations in the forest floor

Nutrient concentration levels from the 1955 measurements are summarized by treatment classes in Table 6.

While some few significant differences show up in the table, there are none to indicate any concentration of nutrient elements due to the presence of ash in the forest floor layer. It is apparent therefore that the ash nutrients leach quickly out of the forest floor. The January plots would be the most likely to show ash nutrients in the forest floor, but it should be remembered that the rains following immediately after the January 1955 burnings were unusually heavy.

The forest floor of the August plots produced a highly significant superiority in potassium concentration. An analysis of

¹⁵See description of effects of August 1954 burnings in "Procedure".

TABLE 6.--Nutrient concentrations in the forest floor from the 1955 measurements

Treatment	Per cent Nitrogen		P.P.M. ^a Calcium		P.P.M. ^a Potassium		P.P.M. ^a Phosphorus	
	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b
Ridge Slope	.8314 .8654	.0725	4601 4872	1162	702 745	81	552 584	38
August burn January burn Check	.8179 .8723 .8550	.0891	4348 4933 4930	1423	825 668 678	100	549 603 551	47
Poisoned Check	.8488 .8480	-	4681 4792	724	719 728	45	566 570	31
RA ^c SA RJ SJ RO SO	.8343 .8014 .7965 .9482 .8634 .8466	.1258	4448 4248 4404 5462 4952 4908	2013	827 822 605 732 675 681	141	541 557 564 642 550 552	67

^aP.P.M. - parts per million.

^bL.S.D. - least significant difference (5 per cent level).

^cTopography - burning treatment combinations.



variance of combined 1953-54 and 1955 potassium data gives a significant fire effect and a significant fire X years effect, both at the 2.5 per cent level. Analysis of the 1953-54 data alone gives no significant effects for any treatments. It is apparent therefore that the potassium superiority of the August plots in 1955 was due mostly, or perhaps entirely, to the August 1954 burnings. The explanation of this phenomenon seems to lie in the abundance of succulent sprouts which followed the August burnings, in the extreme mobility of the potassium ion in the plant, and in the concentration of potassium ions which always occurs in succulent, fast-growing plant parts. Sprouts were very abundant after the August 1954 fires. Many of the sumac and greenbrier (Smilax spp.) sprouts were from 2 to 3 feet long within a month after the fires, and oak sprouts were often 1 to 2 feet high. No doubt potassium concentrated rapidly in these shoots, as explained by Sampson and Samisch (1935), by Meyer and Anderson (1939:422), and by Leyton (1948). When these sprouts were frozen (still in the succulent stage) by the first killing frost of the fall, they must have been very high in potassium content and have added significantly to the potassium concentration of the thin residual forest floor.

Table 6 reveals that the forest floor of the slope-January plots had in general superior concentrations of all the nutrients. For nitrogen, SJ was significantly superior to RJ, and January burning was significantly superior to other burning treatments on slopes. For calcium and potassium, the superiority in the SJ plots was not significant, but the pattern of superiority is nevertheless

apparent in Table 6. For phosphorous, the superiority in the SJ plots was strong enough to cause, without any help from the RJ plots, a significant superiority of January burning over other burning treatments on ridges and slopes combined. This general superiority of the SJ plots in nutrient concentrations of the forest floor is not considered as being due to the slope-January burning treatment. As previously stated, the SJ plots turned out to be unrepresentative as far as past erosion is concerned. It now appears that they were also unrepresentative with respect to litter types. While pine litter was dominant on a majority of all the plots, it dominated on only one of the SJ plots. The other five SJ plots ran heavily to grass litter, to hardwood litter (other than oak), or to greenbrier litter. The 1953-54 data showed approximately the same order of superiority in forest floor nutrient concentrations for the SJ plots as did the 1955 data. There was apparently no effect of hardwood poisoning on nutrient concentration in the forest floor.

Absolute nutrient content of the forest floor

By combining the nutrient concentration data with forest floor weight data, it was possible to calculate actual amounts of forest floor nutrients per acre. These amounts were subjected to the usual statistical analyses.

Table 7 presents pounds of forest floor nutrients per acre from the 1955 data. The pattern of effects shown by this table was apparently dictated primarily by the pattern of forest floor weights and depths. Topographic position and hardwood poisoning showed no significant effects, but non-burned plots had a highly significant

superiority over burned plots, and the January-burned plots had a significant or near-significant superiority over the August-burned plots. An exception to the latter part of this statement can be noted in the case of potassium. Apparently the high concentration of this element in the forest floor of the August plots compensated for the thinness of the floor, giving it an absolute amount of potassium about equal to that in the forest floor of the January plots.

In the statistical analyses combining the 1953-54 data and the 1955 data, the fire effect was highly significant for nitrogen and for calcium, and significant at the 2.5 per cent level for potassium and for phosphorous. The fire X years effect was highly significant for nitrogen, significant for calcium and phosphorous, and not significant for potassium. Analyses of the 1953-54 data alone gave no significance to fire effects for any of the nutrients. Table 8 presents nutrients per acre for fire treatments from the 1953-54 data and from the 1955 data, enabling direct comparison of the two sets of values.

The significant fire X years interactions in the combined analyses make it clear for all nutrients except potassium that the 1954-55 burnings did reduce the supply of nutrients in the forest floor. However, the ultimate effects, as shown by the 1955 data, were accumulative through both the 1951-52 and the 1954-55 burnings. The following is offered in support of this assertion:

1. Fire effects from the 1955 data alone were highly significant for all nutrients. In the much more sensitive

TABLE 7.---Pounds per acre of nutrients in the forest floor from the 1955 measurements

Treatment	Nitrogen		Calcium		Potassium		Phosphorous	
	Mean	L.S.D. ^a	Mean	L.S.D. ^a	Mean	L.S.D. ^a	Mean	L.S.D. ^a
Ridge Slope	71.82	18.21	37.23	10.12	5.93	1.45	4.84	1.18
	66.89		38.28		5.32		4.39	
August burn January burn Check	43.60	22.30	24.91	12.40	4.30	1.78	2.92	1.45
	68.29		35.38		4.87		4.71	
	96.18		52.97		7.71		6.21	
Poisoned Check	70.07	13.37	37.64	7.58	5.57	1.07	4.66	.92
	68.64		37.86		5.69		4.57	

^aL.S.D. - least significant difference (5 per cent level).

TABLE 8.---Pounds per acre of nutrients in the forest floor by fire treatments from the 1953-54 data and from the 1955 data

Treatment	Nitrogen		Calcium		Potassium		Phosphorous	
	1953-54	1955	1953-54	1955	1953-54	1955	1953-54	1955
August burn January burn Check	78.11	43.60	38.88	24.91	9.55	4.30	4.90	2.92
	83.60	68.29	41.99	35.38	9.79	4.87	5.57	4.71
	102.84	96.18	53.88	52.97	11.62	7.71	6.31	6.21

tests combining the 1953-54 and the 1955 data, the fire X years interaction, which tested only the 1954-55 burnings, was highly significant for only one nutrient (nitrogen) and was not significant at all for another (potassium).

2. The differences in nutrient weights among fire treatments were of the same order in 1953-54 as in 1955 (Table 8). However they were of smaller magnitudes. It would seem clear therefore that the 1953-54 differences failed to show significance not because they were not valid, but rather simply because they were not large enough to produce statistical significance at the 5 per cent level in the face of the wide variations within treatments. The actual significance levels attained in 1953-54 for fire treatments were between 10 per cent and 30 per cent for all nutrients.

The Topsoil

Nitrogen and Organic Matter

The soil organic matter tests were not as sensitive as were the tests for total nitrogen. The pattern of results, however, was very similar to that for nitrogen. For this reason, and because of the known close relationship between soil organic matter and total nitrogen, all of the statistical tests applied to the nitrogen results were also applied to the organic matter results.

Scatter diagrams by treatment classes indicated the possibility of a positive relationship between total nitrogen and silt plus clay in the topsoil for the 1955 data. Accordingly a covariance analysis,

with silt-plus-clay per cent as the independent variable, was run for total nitrogen and for soil organic matter. For total nitrogen, the linear regression between plots was significant; the regression between subplots was highly significant. For organic matter, the regression between plots was not significant; between subplots it was highly significant. Means and adjusted means according to various treatment classes, along with least significant differences for adjusted means, are presented in Table 9 for the 1955 data.

Among the unadjusted means for total nitrogen in Table 9, topography was significant, with slopes showing more nitrogen than ridges, and topography X poisoning was highly significant. On the ridges, poisoned subplots were significantly higher in nitrogen than were non-poisoned subplots, whereas on the slopes there was a non-significant difference in the opposite direction.

After the effects of texture were removed through the use of covariance analysis, the adjusted means no longer showed significance for topography. This indicated that the superiority of slopes in total nitrogen was at least partially associated with the heavier textured topsoils of the slopes. Topography X poisoning interaction changed from highly significant to significant, and a significant fire X poisoning interaction developed. The explanation of the topography X poisoning interaction is readily apparent in the fact that poisoned ridge subplots had a highly significant superiority in total nitrogen to non-poisoned ridge subplots, while on the slopes poisoned and non-poisoned subplots were equal in this element. The fire X poisoning interaction was caused by a

TABLE 9.--Total nitrogen and organic matter in the topsoil from the 1955 data

Treatment	Nitrogen in Per Cent			L.S.D. ^b	Organic Matter in Per Cent			L.S.D. ^b
	Means		Adjusted ^a		Means		Adjusted ^a	
	Unadjusted				Unadjusted			
Ridge Slope	.050		.051	.008	2.19	2.23	.41	
	.058		.057		2.41	2.37		
August burn January burn Check	.055		.054	.010	2.35	2.33	.48	
	.057		.056		2.29	2.26		
	.050		.052		2.28	2.33		
Poisoned Check	.055		.056	.005	2.35	2.39	.20	
	.053		.052		2.26	2.22		
Ridge-poisoned Ridge-check Slope-poisoned Slope-check	.054		.056	.007	2.32	2.35	.28	
	.045		.047		2.06	2.10		
	.055		.056		2.38	2.42		
	.060		.057		2.45	2.33		

^aAdjusted for regression with silt-plus-clay per cent in the topsoil.

^bL.S.D. - least significant differences (5 per cent level). Calculated for the adjusted means, but can be used with the unadjusted means since L.S.D.'s for these are only minutely larger.

non-significant inconformity of the non-poisoned January subplots: these showed higher total nitrogen than did the poisoned January subplots while for the other burning treatments, the poisoned subplots showed higher than did the non-poisoned ones.

Analysis of the 1953-54 data gave the same results as analysis of the 1955 data except that topography was highly significant before adjustment for topsoil texture and remained significant after adjustment.

For organic matter, the pattern of differences in treatment means, for both the 1955 data (Table 9) and the 1953-54 data, was substantially the same as for total nitrogen. However, the only near-significant F-ratios (significant at the 10 per cent level) obtained were for topography and for topography X poisoning in the 1953-54 data before adjustment.

From all this, it would seem that in the absence of hardwood poisoning slopes tend to be superior to ridges in soil nitrogen and in soil organic matter. Also, it would appear that poisoning probably caused increased nitrogen and organic matter on the ridges, but had no such effect on the slopes.

The superiority of total nitrogen and organic matter on non-poisoned slopes as compared to non-poisoned ridges is probably due primarily to vegetational differences. The slopes are generally moister than the ridges because they receive sub-surface drainage from the ridges. They should therefore produce a lusher and more diversified growth of vegetation, and such has been demonstrated by

the vegetative data.¹⁶ Organic matter is higher on slopes because more of it is produced there. Nitrogen is higher because there is more organic matter on slopes and because the litter composition is such that it is richer in nitrogen.

An increase in total nitrogen and organic matter following poisoning of larger hardwoods can be explained as being due to two possible causes. Opening of the forest canopy can cause a speed-up in decomposition of the forest floor, thus causing increased nitrogen and organic matter in the mineral soil. Opening of the forest canopy can also cause an increase in herbaceous vegetation whose roots will add nitrogen and organic matter to the soil. Unfortunately neither of these two possibilities can be demonstrated for the ridge plots with the data at hand. As to the reasons for increases on the ridges but not on the slopes after poisoning, only a conjecture can be offered, since the basal area of poisoned hardwoods for the two situations was approximately equal (6.33 sq. ft. per acre on ridges; 6.13 sq. ft. per acre on slopes). It is felt that the explanation must be either (1) that the 5-per cent chance of drawing an abnormal sample from a given population was complied with in this case, or (2) that the amount and composition of litter and vegetation on the slopes was already such that small additional openings in the crown canopy caused no changes leading to increased nitrogen and organic matter in the soil.

It should be noted from Table 9 that no tendency is evident of

¹⁶Slopes were superior to ridges in amount of shrub and vine cover, grass cover, and total cover.

decreasing total nitrogen and organic matter due to burning. Indeed the burned plots showed slight non-significant superiorities over the check plots from both the 1955 data and the 1953-54 data. A combined analysis of the two sets of data showed that in all likelihood the 1954-55 burnings alone had no effects whatsoever on soil nitrogen and soil organic matter.

pH and Mineral Nutrients

Undoubtedly because of mutual relationships to cation exchange capacity, calcium concentration and silt plus clay in the topsoil showed a strong positive linear inter-relationship, as did potassium concentration and silt plus clay. For calcium, the regression was significant between plots and highly significant between subplots; for potassium, regressions were highly significant in both respects. Adjustment of means after covariance analyses eliminated a significant second order interaction for potassium and eliminated a significant first order interaction for calcium. These adjustments were considered as having rather effectively eliminated unwanted variations due to past erosion.

For pH and phosphorous concentration, scatter diagrams and an absence of significant interactions in the variance analyses tended to show an absence of any relationship with silt plus clay in the topsoil. Covariance analyses were not run therefore between these two factors and silt plus clay.

Table 10 gives treatment means from the 1955 data. Calcium and potassium means have been adjusted for soil texture; pH and phosphorous

TABLE 10.--pH and mineral nutrient concentrations in the topsoil from the 1955 data

Treatment	pH		Calcium ^a		Potassium ^a		Phosphorous ^a	
	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b
Ridge	5.58	.18	294.5	85.4	57.6	6.4	1.10	.25
Slope	5.66		348.3		59.6		1.08	
Aug. burn	5.78	.22	350.0	101.9	62.6	7.7	1.36	.31
Jan. burn	5.67		346.1		59.8		1.08	
Check	5.42	.14	268.3	57.7	53.3	4.4	.82	.21
Poisoned	5.65		332.0		59.0		1.14	
Check	5.59		309.8		58.0		1.04	

^aIn parts per million. Calcium and potassium adjusted for silt + clay in the topsoil.

^bL.S.D. - least significant difference (5 percent level).

means have not been adjusted. The phosphorous concentrations are not comparable to concentrations from other studies because of the high ratio of soil used to the extracting solution.

Burned plots were higher than non-burned plots in every category. This superiority was highly significant for pH and for phosphorous, and was significant for potassium. Significance can be assigned to the calcium superiority only at the 10 per cent level, but the superiority is thought to be valid nevertheless because it conforms with the pattern established by the other mineral nutrients. For phosphorous, August burning produced a superiority over January burning which has a probability of only 7 per cent of being due to chance alone.

The increase in pH and in mineral nutrients of the soil after burning was due to the leaching of ash nutrients from the forest floor. Cations displaced hydrogen ions to cause a rise in pH. August burnings, because they consumed more of the forest floor, should have raised the pH and nutrient levels to a greater extent than did the January burnings. From Table 10, such would appear to have actually happened, but the difference has statistical strength only in the case of phosphorous.

Table 11 gives both 1953-54 and 1955 means according to topography and to burning treatments. It permits an assessment of the separate effects of the 1951-52 burnings as compared to the 1954-55 burnings.

In the combined analysis for pH, the fire effect was significant, but the fire X years interaction could be given significance only at

TABLE 11.--pH and mineral nutrient concentrations in the topsoil from the 1953-54 and the 1955 data^a

Treatment	pH		Calcium ^b		Potassium ^b		Phosphorous ^b	
	1953-54	1955	1953-54	1955	1953-54	1955	1953-54	1955
Ridge	5.49	5.58	260.9	280.9	54.2	54.3	1.23	1.10
Slope	5.58	5.66	334.2	361.9	66.2	62.9	1.19	1.08
Aug. burn	5.65	5.78	308.6	356.5	64.8	64.2	1.21	1.36
Jan. burn	5.56	5.67	334.0	358.4	66.8	62.8	1.28	1.08
Check	5.42	5.42	250.2	250.2	48.9	48.9	1.14	.82

^aNo adjustments have been made for silt + clay in the topsoil. However, pH, calcium, and potassium from the 1953-54 data have been adjusted slightly to make the check plot values equal to 1955 values.

^bIn parts per million.

the 10 per cent level, indicating a comparatively weak effect of the 1954-55 burnings. In the analysis of the 1953-54 data alone, the fire effect again showed a 10 per cent probability of having been due to chance, indicating a comparatively weak effect of the 1951-52 burnings. Thus it is apparent that the highly significant effect shown by the 1955 data is in all probability a cumulative effect of both sets of burnings.

In the combined analysis for potassium, the fire effect was significant, but there was no fire X years effect. In the analysis of the 1953-54 data alone, the fire effect was again significant. It would appear from this that the significant fire effect shown by the 1955 data was primarily due to the hotter first series of burnings. The picture is assumed to be approximately the same for calcium, although variations within treatments for this element were too large to permit the development of significant F ratios.

In the combined analysis for phosphorous, the fire effect was significant and the fire X years interaction was highly significant. In the analysis for the 1953-54 data alone, the fire effect was not significant. Thus for phosphorous we have the apparent anomaly of the cooler 1954-55 burnings having had a much more serious effect in adding this element to the soil than did the hotter 1951-52 burnings. The explanation probably lies in the fact that these soils are extremely poor in phosphorous. Given enough time, the vegetation will deplete the soil of any new phosphorous that becomes available. The 1953-54 measurements were made approximately two years after the first burnings, enough time apparently to allow the absorption of

most of the new phosphate by plant roots. The 1955 measurements were made immediately after the last series of burnings.

Attention is called to the apparent superiority of slopes to ridges for pH, calcium, and potassium (Table 11). This superiority is significant at the 5 per cent level only for potassium in 1953-54. Significance at the 10 per cent level however can be assigned to pH and calcium in 1953-54 and to calcium and potassium in 1955. The superiority of the slopes for these three factors is believed to be validly established.

Values in Table 11 can be converted to pounds per acre by the formula:

$$(\text{p.p.m.}) \frac{(43560)(62.428)(1.152)^{17}}{4(1,000,000)} = \text{lbs. per acre.}$$

The burning treatment values for calcium and potassium in 1955 were so converted. Differences were found between August burning and no burning and between January burning and no burning in order to obtain estimates of gains due to burnings. Similar differences were computed for information from Table 7 in order to obtain estimates of losses from the forest floor due to burning. A comparison of losses from the forest floor with gains to the top 3 inches of soil for calcium and potassium shows that the soil has probably retained at least as much of these elements as the forest floor has lost (Table 12). It seems possible that the soil may have retained in addition calcium and potassium released by the fire consumption of live herbs, shrubs, and small trees.

¹⁷Mean volume weight of all soil samples = 1.152.

TABLE 12.--Losses from the forest floor and gains to the top 3 inches of soil (in pounds per acre) of calcium and potassium, 1955 data

Treatment	Calcium		Potassium	
	Loss	Gain	Loss	Gain
August burning	28.06	83.25	3.41	11.98
January burning	17.59	84.74	2.84	10.88

Physical Properties

Total porosity, macroporosity, microporosity

Scatter diagrams indicated strong negative linear relationships of total porosity and macroporosity with silt plus clay. A scatter diagram of microporosity over silt plus clay indicated a very strong positive linear relationship. Accordingly silt plus clay was used as an independent covariant with all three of these factors for the purpose of removing undesired variations. Regression between plots and between subplots was highly significant in every case except one: it was not significant between subplots for total porosity. For both macroporosity and microporosity, adjustment of treatment means after covariance analysis eliminated significant second order interaction. This interaction had been caused by heavy soil textures and correspondingly abnormal porosity values in the SJO group of subplots.

The porosity values were stable throughout all treatments (Table 13). Of particular interest is the stability of the macroporosity values. Macroporosity decreases readily as the result of raindrop impact and of surface runoff. Evidently there was very little exposure of the surface soil due to the treatments. The porosity tests were

very sensitive, as indicated by the small values of the least significant differences (Table 13). The only manner in which sensitivity could have been increased would have been through the taking of more shallow volumetric samples, perhaps 0 to 1-inch samples instead of 0 to 3-inch samples.

TABLE 13.--Total porosity, macroporosity, and microporosity (in per cent of soil volume) for the topsoil from the 1955 data^a

Treatment	Total Porosity		Macroporosity		Microporosity	
	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b
Ridge	55.3	1.8	35.7	1.8	19.6	.9
Slope	56.4		36.5		19.8	
Aug. burn	55.6	2.2	36.4	2.2	19.3	1.1
Jan. burn	56.0		35.8		20.0	
Check	56.2		36.2		19.9	
Poisoned	55.9	1.4	36.1	1.6	19.7	.7
Check	55.8		36.1		19.8	

^aAll values adjusted for relationships with silt plus clay in the topsoil.

^bL.S.D. - least significant differences (5 per cent level).

In an analysis combining the 1953-54 and the 1955 data for macroporosity, only the years effect was significant. Analysis of the 1953-54 data alone gave no significant effects.

Volume weight

Volume weight, or bulk density, depends primarily upon total

porosity and organic matter content. Since total porosity (adjusted for soil texture) was virtually constant throughout all treatments, and since organic matter content was virtually constant for fire treatments and the differences were non-significant for other treatments (Table 9), statistical analysis of volume weights was waived because of foregone results. The mean volume weight of all samples was 1.152 with a 95-per cent confidence interval of $\pm .0232$.

Rate of infiltration

It is unfortunate that measurements were made for infiltration rates only in 1955. A fire X years interaction test for this factor would have been highly indicative and a worthy supplement to the porosity tests. As it turned out, the infiltration rates were highly responsive to past erosion, and it proved impossible to adequately remove this effect sufficiently to bring out treatment effects. For most of the subplots, mean infiltration times varied from 23 to 438 seconds per half liter of water; for the badly eroded subplots, 1SJ0, 2SJ0, 2SJP, and 2SA0, however, mean infiltration times ran from 1130 to 2322 seconds per half liter. There was a highly significant regression of infiltration time with silt plus clay in the topsoil, but after adjustments were made through covariance analysis, these four subplots were still so badly out of line with the others that the corrected error terms were still quite large.

Table 14 gives both unadjusted and adjusted means for different treatments and also gives least significant differences (5 per cent level) for treatment levels. Note the magnitudes of the least significant differences.

TABLE 14.--Infiltration times (in seconds per half liter of water) from the 1955 data

Treatment	Unadjusted		Adjusted ^a	
	Mean	L.S.D. ^b	Mean	L.S.D. ^b
Ridge	122.9	184.8	161.7	168.5
Slope	284.8		246.0	
August burn	220.9	226.2	202.4	201.0
January burn	280.6		245.5	
Check	110.1		161.8	
Poisoned	175.3	154.8	190.1	156.7
Check	232.4		216.2	

^aAdjusted for silt plus clay in topsoil.

^bL.S.D. - least significant difference (5 per cent level).

Vegetative Cover

It should be remembered that line intercepts were laid out and vegetative cover tallied in June, 1954. Thus two growing seasons and the spring of a third had passed since the first burning treatments and the poisoning treatment. The second burning treatments had not yet been applied.

Minor Vegetation

The species of minor vegetation encountered are listed in Appendix C. For purposes of statistical analysis, these were grouped into "forbs", "grasses", and "shrubs and vines". The forbs were mainly

composites and various legumes, with species of Desmodium, Clitoria, Lespedeza, and Galactia being prominent among the latter. The method of tallying forbs only when their stems at the groundline happened to be in the plane of the line intercept proved inadequate for statistical analysis. The principal grasses were little bluestem (Andropogon scoparius Michx.), broomsedge (Andropogon virginicus L.), and panic grasses (Panicum spp.), with bent-awn plumegrass (Erianthus contortus Ell.) and downy oatgrass (Danthonia sericea Nutt.) being important secondary species. In the "shrub and vine" category, the principal species in approximate rank according to cover were cat greenbrier (Smilax glauca Walt.), briars (Rubus spp.), muscadine grape (Vitis rotundifolia Michx.), littleleaf sensitivebrier (Schrankia microphylla (Dryander) Macbr.), Japanese honeysuckle (Lonicera japonica Thunb.), Carolina jessamine (Gelsemium sempervirens (L.) Ait. f.), and Virginia creeper (Parthenocissus quinquefolia L.).

Various factors, including silt plus clay in the topsoil, were plotted against minor vegetation subplot totals in scatter diagrams as a means of isolating possible covariates. No relationship with silt plus clay was evident. A negative relationship with tree canopy plus hardwood reproduction was however evident. This combination factor therefore was used in covariance analyses for grasses and for shrubs and vines (Table 15). Regression with grass cover was highly significant for both plots and subplots. Regression with shrub and vine cover was significant for plots.

TABLE 15.--Grass cover and shrub and vine cover (in percent)

Treatment	Grasses				Shrubs and Vines			
	Not Adjusted		Adjusted ^a		Not Adjusted		Adjusted ^a	
	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b	Mean	L.S.D. ^b
Ridge	1.72		1.43		10.11		9.66	
Slope	1.97	2.11	2.26	1.56	13.41	5.30	13.88	4.52
Aug. burn	2.87		2.07		10.91		9.72	
Jan. burn	1.64	2.59	1.80	1.96	18.37	6.48	18.61	5.66
Check	1.02		1.66		5.96		6.91	
Poisoned	2.09		1.69		13.19		14.24	
Check	1.59	1.51	1.99	1.07	10.30	7.37	9.26	7.71

^aAdjusted for relationship with tree canopy plus hardwood reproduction.

^bL.S.D. - least significant difference (5 percent level).

In studying Table 15, it should be kept in mind that the per cent figures for grasses represent root-crown intercepts while the figures for shrubs and vines represent intercepts of total plants above the ground. The relative sizes of the least significant differences are reflections of the enormous variety in vegetative cover.

The only significant F ratio developed for the grass analyses was for second order interaction (5 per cent level) after adjustment for tree cover. This was attributed to a lack of true representative sampling of the grass population. The major grass species involved are bunch grasses having little ability to compete with woody plants. In consideration of this fact and of the highly significant negative regression of grass cover with tree cover, it seems certain that grass will act only in "taking up the slack" in places where tree and other woody cover has been eliminated.

In the analyses for shrub and vine cover, burned plots had a highly significant superiority over non-burned plots before adjustment for tree cover and a significant superiority after adjustment. January burned plots were significantly superior to August burned plots both before and after adjustment. Thus it would appear that while shrub and vine cover is associated negatively with tree cover it also increases after burning independently of tree cover. The effect is connected with reduction of the forest floor and perhaps with fire-scarification of seed and certain biotic factors. The lesser stimulation after August

burning may have been due to frost-killing of succulent sprouts after the fires, destruction of unripe seed, premature scarification of ripe seed in the duff, or perhaps to other reasons. Stimulation of shrubs and vines by fire was reported by Oosting (1944) on the Piedmont, but no precedent has been found for the greater stimulation of January burning over August burning.

Tree Vegetation

Tree vegetation was divided into two main groups: 6 feet and under in height (reproduction), and over 6 feet in height (overhead canopy). For statistical analyses, species in the reproduction were grouped into "pines", "permanent hardwoods", and "other hardwoods". "Overhead canopy" was analyzed as a single unit. "Pines" consisted of loblolly pine and shortleaf pine. "Permanent hardwoods" were the oaks, the hickories, sweetgum, blackgum, and flowering dogwood, the principal species apt to endure and increase under protection. "Other hardwoods" consisted primarily of persimmon, the sumacs, and sassafras, species known to decrease with protection. The mean cover percentages for these groups are given by treatments in Table 16. Mortality records made after the 1951-52 burnings show that August burning killed 97 per cent of 1-inch (diameter breast high) pines, 60 per cent of 2-inch pines, and 60 per cent of 3-inch pines, and that January burning killed 41 per cent of 1-inch pines but no 2- or 3-inch pines. The analysis of variance for pine reproduction from the line intercept data showed a highly significant superiority of non-burned plots over burned plots (Table 16). This of

TABLE 16.--Pine and hardwood reproduction cover and overhead canopy (in percent)

Treatment	Pines ^a		"Permanent" Hardwoods ^b		Other ^c Hardwoods		Overhead Canopy ^d	
	Mean	L.S.D. ^e	Mean	L.S.D. ^e	Mean	L.S.D. ^e	Mean	L.S.D. ^e
Ridge	1.34	1.41	11.22	6.87	10.54	5.60	64.4	11.5
Slope	1.65		11.13		10.79		69.8	
Aug. burn	.40	1.71	13.96	8.44	12.10	6.84	57.2	14.1
Jan. burn	.69		11.10		13.08		69.8	
Check	3.39		8.44		6.79		74.1	
Poisoned	1.41	1.81	10.24	3.80	12.43	4.91	64.2	9.7
Check	1.57		12.09		8.89		69.9	

^a Loblolly and shortleaf pines 6 feet and less in height.

^b Oaks, gums, hickories, and dogwood 6 feet and less in height.

^c Mainly persimmon, sumacs, and sassafras 6 feet and less in height.

^d All trees over 6 feet in height.

^e L.S.D. - least significant difference (5 percent level).

course was to be expected. The purpose of including the pine analysis at this point was to let it serve as a rough indication of the sensitivity of the hardwood reproduction analyses of data from the line intercepts.

The only significant F ratio obtained from the two hardwood analyses was for second order interaction (5 per cent level) in "permanent hardwoods". After thorough examination of the means for basic treatment combinations, it was decided that this was due to a lack of truly representative sampling at the basic level.

Examination of hardwood reproduction cover by burning treatments (Table 16) makes it apparent that new growth had at least replaced all hardwood vegetation up to 6 feet high killed by the 1951-52 fires (Figures 14 through 19). This was true for "permanent hardwoods" as well as for the more invasive "other hardwoods". The new growth was observed to be predominantly of sprout origin and often gave the impression in the field that it had come back "thicker than ever". This heavy resurgence of hardwood sprouts after single fires on upland soils is in common with the experiences of Brender and Nelson (1954), Oosting (1944), and Wenger (1955) in other areas.

In the analysis for overhead canopy, fire effects gave an F ratio indicating a probability of 94 per cent that different populations were involved. Individual tests of burning vs. non-burning and August burning vs. January burning gave significance only at the 10 per cent level. The unconventional test of August burning vs. other burning treatments produced an F ratio indicating



Fig. 14.-View in Plot 2RA before the first August burn. Species in the undergrowth are mostly oaks.



Fig. 15.-Same view as Fig. 14. Taken in the early spring following the fire.



Fig. 16.--Same view as Figs. 14 and 15, three years after the fire. Hardwood growth is reduced in height but not in density. Pine litter fuel is probably ample for a new fire.



Fig. 17.--View in Plot 6RA before the first August burn. Stocking of overstory pine was very poor in this plot.



Fig. 18.-Same view as Fig. 17. Taken in the early spring following the fire.



Fig. 19.-Same view as Figs. 17 and 18, three years after the fire. Shrubby vine in foreground is Smilax glauca. Fuel here is insufficient for a new hardwood control fire.

a probability of 98 per cent that different populations were involved. This test was accepted as valid in this case since it was known that the August burnings took a rather heavy toll of sapling-size trees. January burnings took such a light toll that normal crown closure may have cancelled their effect by the time the line intercept tallies were made.

Moore's Results

Table 17 summarizes the results obtained by Moore (1956) in his spring 1955 survey of the non-poisoned subplots. In studying these results, the following should be kept in mind:

1. Moore's survey followed the second series of burnings. His results contain some cumulative effects of both series of burnings and possibly some highly temporary effects from just the last burnings (1954-55).
2. Moore tallied two strata along his line intercepts, an herb-low vine stratum and a "canopy" stratum including all other vegetation.
3. Moore measured total plant interception on herbs as well as woody plants. Measurements were made so soon after the last burnings that there was some question as to whether or not bunch grass rootstocks had had time to regrow destroyed tops to their full horizontal expansions.

This study brought out that both burning treatments favored legumes, composites, and euphorbs (Table 17). Many of the species of these groups are hardy and prolific invaders, and leguminous

seed often receive necessary scarification from fire (Stoddard, 1935).

TABLE 17.--Statistical results obtained by Moore (1956) in his spring 1955 vegetative survey^a

Plant Group	Fire vs. No Fire		August vs. January burn		Ridge vs. Slope		Inter- action
	F ^b	O	A	J	R	S	F x T
Desmodium			*				
Lespedeza	*						
Galactia volubilis	*			*			
Euphorbs	*						
Compositae	**		*				
Pine seedlings		*					
Smilax glauca						*	
Andropogons						*	
Andropogons adj. ^c		*				**	*
Canopy		*					
Space			**		*		

^a* indicates significance at the 5 per cent level; ** indicates significance at the 1 per cent level. Asterisks are placed under the treatments which showed superiority.

^bLegend for treatments: F - fire, O - no fire, A - August burn, J - January burn, R - ridge, S - slope, T - topography.

^cAdjusted for linear relationship with canopy.

Smilax glauca is shown as unaffected by fire and as being more abundant on slopes than on ridges (Table 17). This species was the principal one in the writer's "shrubs and vines" category which showed

a highly significant superiority on burned plots as compared to check plots (Table 15). It is of course entirely possible that species other than Smilax glauca in the category caused the superiority. More than likely, however, Smilax glauca and similar species were superior on the burned plots previous to the 1954-55 fires, received a temporary setback as the result of the fires, and will again show even greater stimulation after one or two full growing seasons. "Shrubs and vines" (Table 15), like Smilax glauca (Table 17), were superior on slopes as compared to ridges.

Andropogons are shown as superior on slopes and as superior on non-burned plots when adjusted for "canopy" (Table 17). The writer feels that the latter result was due either to Moore's system and time of measurement (no. 3 above) or to an actual though highly temporary tendency toward a forb stage in succession to be soon displaced by stages in which grasses and other higher plants will again predominate. According to Bruce (1947), Heyward (1937), Lemon (1949), Wells (1928), Oosting (1944), and Buell and Cantlon (1953), the Andropogons should increase after burning.

Growth Response of Pines

The one full year (1955) of dendrometer growth measurements was summed for each tree and converted to basal area. The mean basal area growth per tree by topography classes was:

Ridges	.0286 square feet
Slopes	.0299 square feet

with a least significant difference (5 per cent level) of .0052 square

feet. Growth per tree by fire treatments was:

August burned	.0300 square feet
January burned	.0290 square feet
Check	.0288 square feet

with a least significant difference of .0064 square feet. Growth per tree by poisoning treatments was:

Poisoned	.0317 square feet
Check	.0268 square feet

with a least significant difference of .0052 square feet.

Only the difference due to poisoning is worth considering as a real difference. The probability that it is due to random variation alone is only 6 per cent. Apparently the light release given by hardwood poisoning in 1952 caused pine growth stimulation that extended through 1955.

If the burning treatments caused any stimulation of growth due to added soil nutrients, this test has not been sensitive enough to detect it. It is believed that calcium and potassium were not significant growth factors for these pines but that phosphorous might have been. It should be remembered however that drought conditions were common from 1952 through 1955 and that in all likelihood soil moisture was generally the most significant growth factor. This would account for the surprising release effect of the light poisoning treatment of 1952.

GENERAL CONCLUSIONS

From this exploratory study, it can be stated tentatively that prescribed burning can be done on the Gulf upper coastal plain without significant harm to the soil. At least such can be said with reference to the soil types found in the Fayette Experiment Forest and with reference to the many closely related soil types found throughout the Upper Coastal Plain region of Alabama.

Net losses of total nitrogen and organic matter have occurred, but these have been from the forest floor and not from the mineral soil. Meanwhile there is considerable indication that new sources of nitrogen and organic matter are developing in the stimulated growth of legumes and other forbs. Grasses were shown to have a close negative relationship with the total density of higher plant forms and should eventually increase in density if the higher forms decrease under the influence of continued burning. Decaying grass roots will then be another source of organic matter to the soil. The future trend of total nitrogen and organic matter is only indicated with present data however. It should be checked with future measurements.

Loss of mineral nutrients through leaching does not appear to have occurred. The top 3 inches alone of the mineral soil retained more added nutrients than were lost by the forest floor. The addition of mineral nutrients from fire-consumed living plants should be a forceful reminder that we can never properly assess the nutrient status

of a forest unless we know what is in the living plants as well as what is in the forest floor and the soil.

The soil physical properties apparently did not change, yet these should be watched very closely under a prolonged burning program. Surface sealing and loss of macro-porosity in the top 1/4 inch of soil may have occurred under some conditions and not have been detected through the use of volumetric samples of the top 3 inches of soil. Such deterioration, if present, will have been very slight, but if the conditions causing it continue, the deterioration will be accelerative. Steeper slopes and areas having suffered past erosion under cultivation are the most hazardous. It can be said, however, that these should be reasonably safe from physical deterioration if approximately 1/2 inch of forest floor remains intact after burning.

While August burning is more apt to expose the mineral soil than January burning, where the canopy is moderately dense the period of danger will be short because of the nearness to normal autumn leaf cast. If one relies on this fact for protection however, he should remove much of the risk by burning no earlier than mid-September instead of burning in August. From the vegetation standpoint, August burning is superior to January burning because it reduces hardwoods more effectively for a given amount of fuel consumption and because it stimulates shrubs and vines less.

Fuel accumulation and fuel types are the primary factors involved in successful prescribed burning. To put the problem in more familiar terms and in the form of a question, which vegetational types at what

minimum densities can be burned frequently enough for effective hardwood control without exposing the topsoil to physical deterioration? Future investigations should be aimed at answering this question. The standards will have to vary somewhat for differences in site, particularly for differences in slope and in past erosion.

Experimental control can be greatly improved in the future through the use of much smaller plots. In the past it has been thought that at least 5 acres should be burned as a unit in order to obtain typical burning effects. The replication of such units containing truly similar 2-acre plots in their centers is almost impossible in the Upper Coastal Plain region. Experience has taught that the controlled backfire develops its typical intensity within a few yards of the line of ignition. There is no reason why, say, .1-acre plots with suitable isolation strips cannot be used. Such plots can be placed within relatively uniform and rather narrowly defined conditions that can be replicated.

APPENDIX A. NOTES ON FUEL TYPES AND THEIR REACTIONS

DURING THE AUGUST BURNINGS, 1954

Grass.--This type exhibited the most rapid and complete burning of all. Dead grass at the bases of the green clumps was abundant and loosely packed. Burning of both dead and green grass was usually complete.

Pine forest floor.--Combustion was rarely complete, and then only in very small areas of a foot or less in diameter. Usually there were at least small pieces of uncharred needles, and sometimes tiny patches of wholly unscorched needles, left beneath the ashes and charred needles. Usually needles lying beneath flat-lying pieces of bark were not scorched at all.

Hardwood forest floor.--Dogwood litter seemed resistant to burning, and combustion percentage was always low. Other hardwood litter burned readily enough at the surface layers, but leaves in lower layers were often left intact; in fact, the lower layers were often left completely undisturbed.

Smilax.--There were often dead vines and dead leaves hung among the Smilax briars. Where abundant enough, these caused minor "flare-ups" in the burning. Green Smilax leaves and branches seemed to be as resistant to burning as green shrubs and vines in general.

Pine slash with dead needles still retained.--This fuel type produced by far the hottest and most intensive "flare-ups", with the heat and size of the conflagration dependent of course on the amount of the slash in any one spot.

Forbs.--Most forbs were green and had little dead residue around them. Most were consumed after drying out from the heat of the fire.

Live woody plants--small trees, shrubs, and vines (other than Smilax).--These added to the fuel only if they were first dried out by the fire itself. This happened where dead fuels were abundant and not packed in tight layers. Open-crowned species, such as the sumacs, suffered the most combustion.

APPENDIX B. EXAMPLES OF STATISTICAL ANALYSES

Tables 18 and 20 give examples of typical statistical analyses used in this study. The covariance analysis in Table 18 follows the method outlined by Federer (1955). Analyses of variance are after Snedecor (1946).

Regression coefficients for main linear regressions were computed from Table 18 as follows:

$$b_a = \frac{\sum XY \text{ (Error a)}}{\sum X^2 \text{ (Error a)}} = \frac{4741.73}{2987.70} = 1.5871$$

$$b_b = \frac{\sum XY \text{ (Error b)}}{\sum X^2 \text{ (Error b)}} = \frac{2010.03}{1116.21} = 1.8008$$

where b_a and b_b = regression coefficients between plots and between subplots respectively.

Fiducial limits and least significant differences for adjusted means were computed from Table 18 in accordance with the following example for fire means:

Corrected Error a term for fire

$$\text{means} = \text{adjusted Error a} \left(1 + \frac{\text{M.S. of } \sum X^2 \text{ (fire)}}{\sum X^2 \text{ (Error a)}} \right)$$

$$= 158.07 \left(1 + \frac{147.57}{2987.70} \right) = 165.88$$

$$95 \text{ per cent fiducial limits} = t \text{ (for 24 d.f.) } \sqrt{\frac{165.88}{N \text{ (fire)}}}$$

$$= 2.064 \sqrt{\frac{165.88}{24}} = \pm 5.43 \text{ p.p.m.}$$

Least significant difference (fire)

$$= 5.43 \sqrt{2} = 7.66 \text{ p.p.m.}$$

Adjustment of means was accomplished as outlined in Table 19.

TABLE 18.--Analysis of variance for soil potassium (Y), 1955 data, and covariance with silt plus clay (X)

Source of Variation	d.f.	X	XY	Y
		$\sum X^2$	$\sum XY$	$\sum Y^2$
1. Total	71	6216.47	11,595.77	29,774.76
2. Blocks (B)	5	775.96	1,756.13	4,519.67
3. Topography (T)	1	315.85	654.31	1,355.47
4. Fire (F)	2	295.14	972.11	3,494.40
5. T x F	2	298.88	567.92	1,079.91
6. Error a (E_a)	25	2987.70	4,741.73	11,319.17
7. Poison (P) ^a	1	74.42	99.84	133.94
8. P x F	2	64.49	116.01	215.36
9. P x T	1	92.93	183.59	362.70
10. P x T x F	2	194.89	494.10	1,389.80
11. Error b (E_b)	30	1116.21	2,010.03	5,904.34
12. $E_a + E_b$	55	4103.91	6,751.76	17,223.51
13. $E_a + E_b$ (usual regression method)				
14. E_a vs. E_b (13)-(12)				
15. T + E_a	26	3303.55	5,396.04	12,674.64
16. Topography, adjusted (15)-(6)				
17. F + E_a	27	3282.84	5,713.84	14,813.57
18. Fire, adjusted (17)-(6)				
19. (T x F) + E_a	27	3286.58	5,309.65	12,399.08
20. T x F, adjusted (19)-(6)				
21. P + E_b	31	1190.63	2,109.87	6,038.28
22. Poison, adjusted (21)-(11)				
23. (P x F) + E_b	32	1180.70	2,126.04	6,119.70
24. P x F, adjusted (23)-(11)				
25. (P x T) + E_b	31	1209.14	2,193.62	6,267.04
26. P x T, adjusted (25)-(11)				
27. (P x T x F) + E_b	32	1311.10	2,504.13	7,294.14
28. P x T x F, adjusted (27)-(11)				

TABLE 18.--Continued

Y (cont.)		Reduction		Error of Estimate			
M.S.	F	Y ²	F	d.f.	Y/X	M.S.	F
903.93	2.00	3974.42		4	545.25	136.31	
1355.47	2.99	1355.46		0	.01	0	
1747.20	3.86*	3201.86		1	233.90	233.90	
539.96	1.19	1079.14		1	.77	.77	
452.77		7525.52	47.61**	24	3793.65	158.07	
133.94	.68	133.94		0	0	0	
107.68	.55	208.69		1	6.67	6.67	
362.70	1.84	362.70		0	0	0	
694.90	3.53*	1252.68		1	137.12	137.12	
196.81		3619.59	45.94**	29	2284.75	78.78	
				53	6078.40	114.69	
		11108.01		54	6115.50		
				1	37.10	37.10	.32
		8813.93		25	3860.71		
				1	67.06	67.06	.42
		9945.04		26	4868.53		
				2	1074.88	537.44	3.40*
		8578.03		26	3821.05		
				2	27.40	13.70	.09
		3738.82		30	2299.46		
				1	14.71	14.71	.19
		3828.28		31	2291.42		
				2	6.67	3.34	.04
		3979.66		30	2287.38		
				1	2.63	2.63	.03
		4782.75		31	2511.39		
				2	226.64	113.32	1.44

TABLE 19.--Adjustment of soil potassium means^a (Y) for regression with silt + clay^b (X)

Treat- ment	X	x_1^c	$b_a x_1$	Y	$Y - b_a x_1$	x_2^d	$b_b x_2$	$Y - b_b x_2$
A	30.0	1.0	1.6	64.2	62.6	-	-	-
J	30.9	1.9	3.0	62.8	59.8	-	-	-
O	26.2	-2.8	-4.4	48.9	53.3	-	-	-
R	26.9	-2.1	-3.3	54.3	57.6	-	-	-
S	31.1	2.1	3.3	62.9	59.6	-	-	-
P	28.0	-	-	57.2	-	-1.0	-1.8	59.0
O	30.1	-	-	60.0	-	1.1	2.0	58.0

^aIn parts per million.

^bIn per cent of total oven-dry weight.

^cDeviations from the grand mean. $\bar{X} = 29.0$.

^dDeviations from means adjusted for regression between plots. For total P vs. total O, no adjustment is necessary and $\bar{X} = 29.0$ is used.

TABLE 20.--Analysis of variance for soil potassium, 1953-54 and 1955 data combined

Source of Variation	d.f.	Sum of Squares	M.S.	F	p ^a
1. Total	71	53,927.60			
2. Blocks (B)	5	9,369.92	1873.98	1.87	.10
3. Fire (F)	2	7,971.73	3985.86	3.97	.05
4. Topography (T)	1	3,846.38	3846.38	3.83	.10
5. T x F	2	1,754.74	877.37	.87	.30
6. Error a	25	25,113.21	1004.53		
7. Years (Y)	1	4,330.19	4330.19	93.95	.01
8. F x Y	2	111.29	55.64	1.21	.10
9. T x Y	1	99.05	99.05	2.15	.10
10. T x F x Y	2	48.90	24.45	.53	.30
11. B x Y	5	129.83	25.97	.56	.30
12. Error b	25	1,152.36	46.09		

^aProbability of variation being due to random sampling alone.

APPENDIX C. SPECIES OF MINOR VEGETATION

Table 21 lists the common non-arboreal spermatophytes found in the Fayette Experiment Forest. The list is a composite of species found by Moore (1956) and by the writer. Unless otherwise noted, scientific and common names are in agreement with "Standardized Plant Names" (Kelsey and Dayton, 1942).

TABLE 21.--The common non-arboreal spermatophytes of the Fayette Experiment Forest

Scientific Name	:	Common Name
Anacardiaceae		
Toxicodendron quercifolium Greene		Poisonoak
Toxicodendron radicans Ktze.		Common poisonivy
Caprifoliaceae		
Lonicera japonica Thunb.		Japanese honeysuckle
Compositae		
Ambrosia artemisiifolia L.		Common ragweed
Aster spp.		Asters
Chrysopsis graminifolia (Michx.) Ell.		Grassleaf goldenaster
Coreopsis major Walt.		Trefoil coreopsis
Elephantopus tomentosus L.		Tobaccoweed ^a
Erigeron canadensis L.		Horseweed fleabane
Erigeron strigosus Muhl.		White-top fleabane
Eupatorium album L.		Eupatorium
Eupatorium leucolepis (DC.) T. & G.		Eupatorium
Gnaphalium uliginosum L.		Low cudweed
Helianthus sp.		Sunflower
Rudbeckia serotina Nutt.		Black-eyed Susan
Senecio smallii Britt.		Groundsel
Silphium gatesii Mohr.		Rosinweed
Solidago odora Ait.		Sweet goldenrod

TABLE 21.--Continued

Scientific Name	Common Name
Convolvulaceae	
<i>Breweria humistrata</i> (Walt.) Gray	Breweria
<i>Ipomoea pandurata</i> (L.) G.F.W. Mey.	Bigroot morningglory
Ericaceae	
<i>Vaccinium</i> spp.	Blueberry
Euphorbiaceae	
<i>Euphorbia corollata</i> L.	Flowering spurge
<i>Tragia urticifolia</i> Michx.	Noseburn
Graminae^b	
<i>Andropogon scoparius</i> Michx.	Little bluestem
<i>Andropogon virginicus</i> L.	Broomsedge
<i>Danthonia sericea</i> Nutt.	Downy oatgrass
<i>Erianthus alopecuroides</i> (L.) Ell.	Silver plumegrass
<i>Erianthus contortus</i> Ell.	Bent-awn plumegrass
<i>Panicum</i> spp.	Panic grass
Guttiferae	
<i>Ascyrum</i> sp.	St. Peterswort
<i>Hypericum</i> sp.	St. Johnswort
Leguminosae	
<i>Cassia fasciculata</i> Michx.	Partridge-pea ^a
<i>Centrosema virginianum</i> (L.) Benth.	Coastal butterflypea
<i>Clitoria mariana</i> L.	Atlantic pigeonwing
<i>Crotalaria sagittalis</i> L.	Arrow crotalaria
<i>Desmodium laevigatum</i> (Nutt.) DC.	Smooth tickclover
<i>Desmodium marilandicum</i> (L.) DC.	Maryland tickclover
<i>Desmodium Nuttallii</i> (Schindl.) Schub. ^a	Tickclover
<i>Desmodium paniculatum</i> (L.) DC.	Panicled tickclover
<i>Desmodium rigidum</i> (Ell.) DC.	Tickclover
<i>Desmodium rotundifolium</i> DC.	Roundleaf tickclover
<i>Desmodium viridiflorum</i> (L.) DC.	Velvetleaf tickclover
<i>Galactia volubilis</i> (L.) Britt.	Downy milkpea
<i>Lespedeza hirta</i> (L.) Hornem.	Hairy lespedeza
<i>Lespedeza intermedia</i> (S. Wats.) Britt.	Wand lespedeza
<i>Lespedeza Nuttallii</i> Darl.	Lespedeza
<i>Lespedeza procumbens</i> Michx.	Trailing lespedeza
<i>Lespedeza repens</i> (L.) Bart.	Creeping lespedeza
<i>Lespedeza stuevei</i> Nutt.	Stuves lespedeza
<i>Lespedeza virginica</i> (L.) Britt.	Slender lespedeza
<i>Rhynchosia erecta</i> (Walt.) DC.	Erect rhynchosia

TABLE 21.--Continued

Scientific Name	Common Name
<i>Rhynchosia intermedia</i> (T. & G.) Small	Rhynchosia
<i>Schrankia microphylla</i> (Dryander) Macbr.	Littleleaf sensitivebrier
<i>Strophostyles helvola</i> (L.) Ell.	Trailing wildbean
<i>Stylosanthes biflora</i> (L.) BSP.	Pencilflower
<i>Tephrosia spicata</i> (Walt.) T. & G.	Brownhair tephrosia
<i>Tephrosia virginiana</i> (L.) Pers.	Virginia tephrosia
Liliaceae	
<i>Smilax glauca</i> Walt.	Cat greenbrier
Loganiaceae	
<i>Gelsemium sempervirens</i> (L.) Art. f.	Carolina jessamine
Rhamnaceae	
<i>Ceanothus americanus</i> L.	New Jersey tea ^a
Rosaceae	
<i>Crataegus</i> spp.	Hawthorn
<i>Prunus angustifolia</i> March.	Chickasaw plum
<i>Prunus cuneata</i> Raf. ^c	Dwarf-cherry ^c
<i>Rosa</i> sp.	Rose
<i>Rubus</i> spp.	Blackberry
Solanaceae	
<i>Physalis heterophylla</i> Nees	Clammy groundcherry
Vitaceae	
<i>Parthenocissus quinquefolia</i> L.	Virginia creeper
<i>Vitis vulpina</i> L.	Chicken grape
<i>Vitis rotundifolia</i> Michx.	Muscadine

^aAfter Fernald (1950).

^bAfter Hitchcock (1935).

^cAfter Small (1933).

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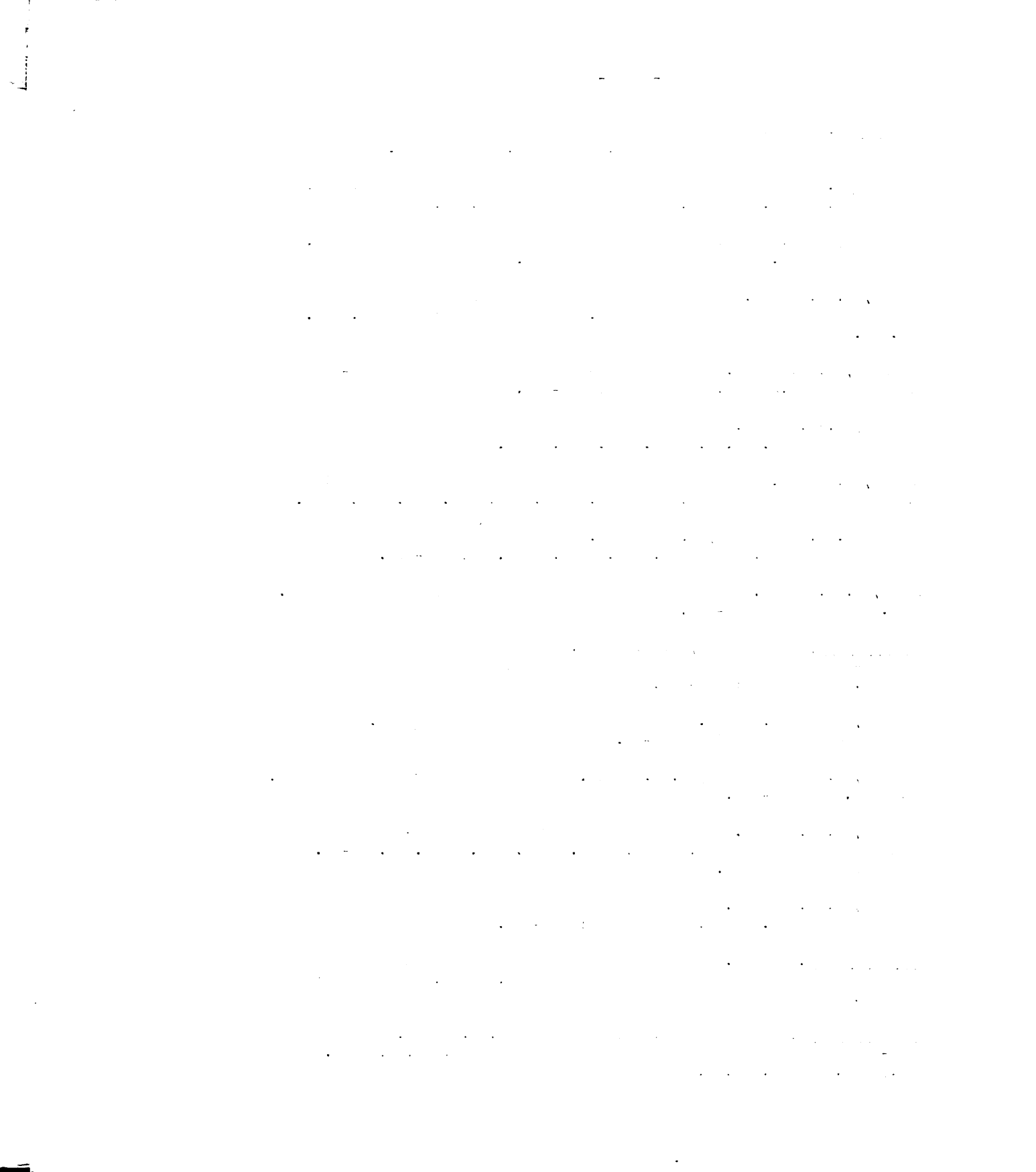
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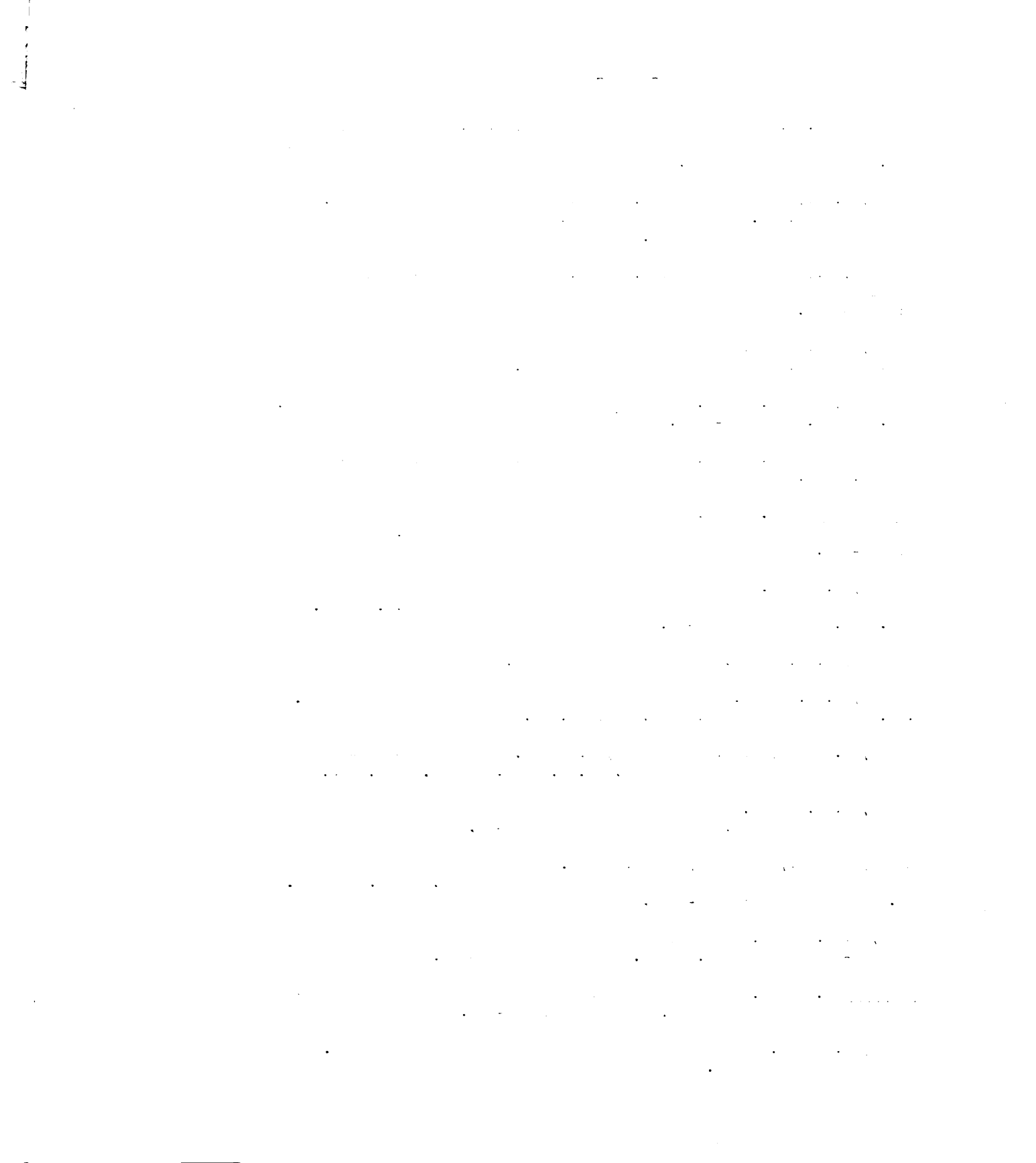
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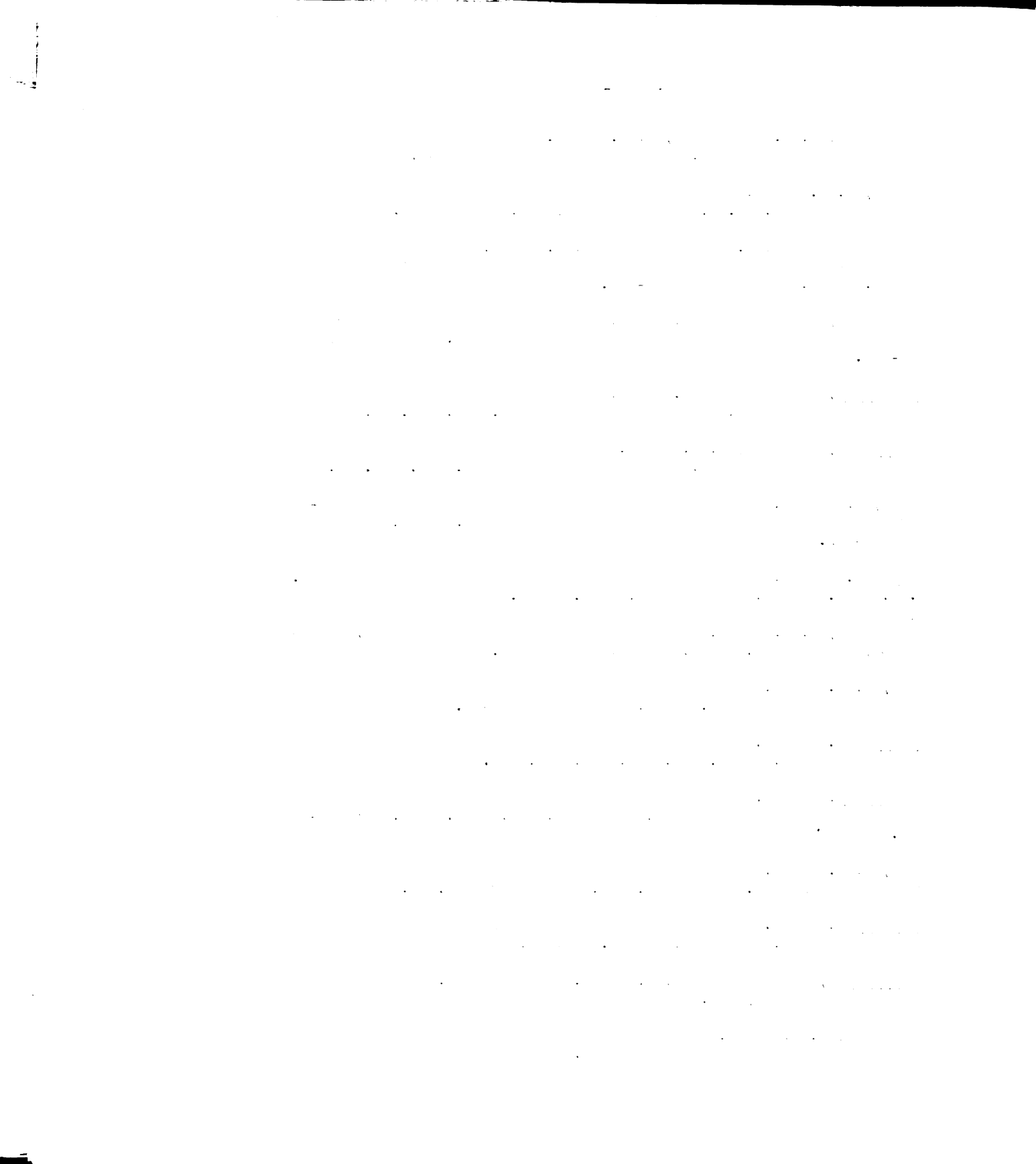
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