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Long-Term Studies of Prescribed Burning in Loblolly Pine Forests of the Southeastern Coastal Plain

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ABSTRACT

Prescribed fire provides many benefits in southern pine stands. A study begun in 1946 provides a unique opportunity to observe long-term changes in understory vegetation, soil properties, and overstory tree growth caused by repeated burning.

Keywords: Backing fire, headfire, understory hardwoods, nitrogen, phosphorus, calcium, basal area.

Introduction

Fire has been a major ecological force in the evolution of southern forests. As a result, plant communities in the South not only tolerate fire, but actually require it to exist (Cooper 1961). Evidence of early fires can be found as buried layers of charcoal in peat beds (Cooper 1961), in scars from lightning strikes on petrified trees (Komarek 1974), and in the writings of early travelers (Bartram 1791). Indians and early European settlers often used fire to drive game and improve habitat for both wild and domestic animals. These fires also helped control insects and dense underbrush.

Today, prescribed fire--fire set under planned conditions to accomplish specific management objectives--is an accepted tool for the management of southern pine forests. Like the Indians and early settlers, foresters use fire to improve habitat for wild and domestic animals and to control the density of understory vegetation. Prescribed burning provides several benefits to forest management: it consumes living and dead fuels (fig. 1), reducing the incidence and damage of wildfires; it can improve growth rates of overstory pines by killing vegetation that would otherwise compete for water and nutrients; it prepares sites for seeding or planting; and it controls certain diseases of pines. During the past decade, the area prescribed burned each year in the South has increased from 0.8 million ha to over 2 million ha (Wade 1985).

Figure 1.--Low-intensity prescribed fires provide multiple benefits for southern pine forests.

Even though prescribed burning is accepted today, its widespread use is relatively new. Fire protection policies of the U.S. Department of Agriculture, Forest Service, State forestry agencies, and forest industry prevented the use of prescribed fire in the early decades of the 20th century. Even light burning was prohibited on the newly established national forests of the South. Prescribed burning for fuel reduction gained acceptance in the 1940's and 1950's, but only after a series of wildfires showed the disastrous consequences of fire exclusion (Pyne 1982). As fire use in southern forests increased, so did the need for a better understanding of its long-term effects on forest ecosystems.

An ongoing experiment by the Southeastern Forest Experiment Station is providing the most comprehensive available information about changes to southern pine ecosystems caused by repeated burning over a long period. The experiment, known as the Santee Fire Plot Study, was established in 1946. This paper summarizes the observed effects on understory vegetation, soil properties, and overstory tree growth.

Description of the Study

Study plots are on the Santee Experimental Forest in Berkeley County, SC, and on the Westvaco Woodlands in neighboring Georgetown County. Both areas are on a Pleistocene terrace on the lower Coastal Plain at 7.5 to 9.0 m above sea level. Soils include a variety of series but are generally described as poorly drained Ultisols of medium to heavy texture. Soils are considered productive with a site index of 27 to 30 m for loblolly pine at age 50. In 1946, forests of both study sites consisted of unmanaged, but well-stocked, even-aged stands of loblolly pine. The Santee stand was 42 years old when the study was initiated, while the Westvaco stand was 36 years old. Both stands had resulted from natural regeneration after logging.

Six treatment plots, 0.1 ha in size, were established in each of five replications. Three replications are on the Santee Experimental Forest and two are on the Westvaco woodlands. Treatments include: (1) periodic winter burning, (2) periodic summer burning, (3) biennial summer burning, (4) annual winter burning, (5) annual summer burning, and (6) an unburned control.

All winter burning was done on December 1 or as soon afterward as weather permitted. Summer burning was done on or soon after June 1. Annual burning has continued since December 1946 for a total of 41 consecutive years. Periodic burns are conducted when 25 percent of the understory hardwood stems reach 2.5 cm in diameter at breast height (d.b.h.). This prescription has resulted in variable burning intervals ranging from 3 to 7 years. At present, seven periodic burns have been conducted. Biennial summer burning was added to the study in 1951 and it has been done 19 times to date.

Burning techniques were selected to ensure complete coverage of the plot by fires of the lowest practical intensity. Selection was made

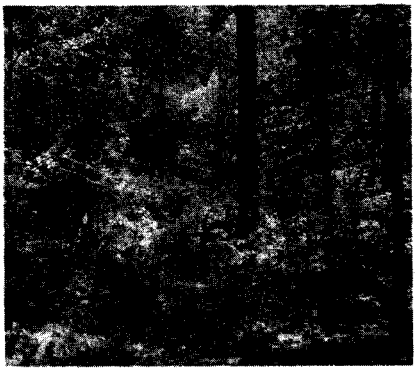
at the time of burning based on prevalent fuel and weather conditions. In general, backing fires (slow moving, cool fires that back into the wind) were used on periodically burned plots having thick underbrush or when hot and dry weather increased the risk of high-intensity fires. Headfires (fast-moving fires burning in the same direction as the wind) or strip headfires (several headfires parallel to each other) were used on annually burned plots with little underbrush and when fuels were too moist to support a backing fire.

Understory Vegetation

Since fire has been a component of southern forests for millennia, most native plants have adapted to its presence and are not eradicated by prescribed fires. However, density of each species can be affected. Because different plant species have different adaptive strategies to fire, the various combinations of season and frequency of burning on the Santee fire plots have produced obvious differences in structure and species composition of understory vegetation (fig. 2).

Unburned control plots (fig. 2A) have been undisturbed for approximately 80 years. Understory vegetation consists almost entirely of large tree and shrub species adapted to living in the shade of overstory pines. Practically every size class of hardwoods from 2.5 to 50 cm d.b.h. is represented in control plots.

Periodic winter burns (fig. 2B) and periodic summer burns (fig. 2C) have created two distinct size classes of understory vegetation. Hardwoods over 15 cm d.b.h. are as common on periodically burned plots as they are on unburned controls. At the beginning of the study, these trees were old enough to be protected by thick bark and tall enough that their buds were above the intense heat of the first fire. Understory hardwoods over 15 cm d.b.h. have survived on all treatment plots. The other common size class is composed of stems less than 5 cm d.b.h. The



A. Unburned Control

B. Periodic Winter Burn

C. Periodic Summer Burn

D. Annual Winter Burn

E. Biennial Summer Burn

F. Annual Summer Burn

Figure 2.--Understory vegetation on the Santee fire plots after 36 to 41 years of prescribed burning by various combinations of season and frequency.

aboveground portions of these trees are generally too small to survive most fires, but their root systems survive and produce sprouts after each fire. Burns have been frequent enough to prevent the growth of sprouts into a larger size class. Only a few individuals between 5 and 15 cm are present on periodically burned plots. Trees of this size class are susceptible to top-kill from occasional flareups or hotspots in the fire. Since hotspots occur more often during the summer, fewer trees of this intermediate size class have survived in plots burned in the summer than in those burned in the winter.

Study plots burned annually in winter (fig. 2D) or biennially in summer (fig. 2E) have large numbers of hardwood and shrub stems less than 1 m tall. During each fire, these stems are top-killed. However, both of these treatments allow the vegetation at least one full growing season to recover from fire. Many root systems survived these treatments and resprouted. Biennial summer burns generally led to greater coverage by grasses than annual winter burns.

Annual summer burning has nearly eliminated understory woody vegetation (fig. 2F). Burning has been frequent enough and of sufficient intensity to kill root systems of all hardwood and shrub species, and the understory is dominated almost entirely by grasses and forbs. Seedlings of hardwood and shrub species appear occasionally, but they do not survive the next fire.

The Southeastern Forest Experiment Station has monitored changes in understory vegetation caused by burning since the study was established. Previous descriptions of various vegetative characteristics have been given by Chaiken (1949), Cushwa and others (1966), Lewis and Harshbarger (1976), and Lotti and others (1976). The most recent survey of understory characteristics was completed by Langdon (1981) after 30 years of prescribed burning. The understory has changed little since the 30th

year of the study, so Langdon's results are summarized here.

The total number of hardwood stems less than 2.5 cm d.b.h. has been significantly increased by most burning treatments (fig. 3). In general, the greater the frequency of burning the greater the number of small hardwood stems. When fires top-kill small trees, surviving root systems often produce multiple sprouts, causing a net increase in the total number of stems per hectare. Numbers of sweetgum, one of the most prolific sprout-producing species in the Southeast, changed most dramatically. Total number of stems of all species in annual winter burn plots is nearly five times greater than in unburned plots. The exception to this trend is annual summer burning. Top-kill early in the growing season halts carbohydrate production when carbohydrate reserves normally in the root system are at their lowest levels. When summer burns are repeated annually, carbohydrate reserves are eventually depleted and root systems die. The only small hardwoods present after annual summer burns are those germinated from seed between fires.

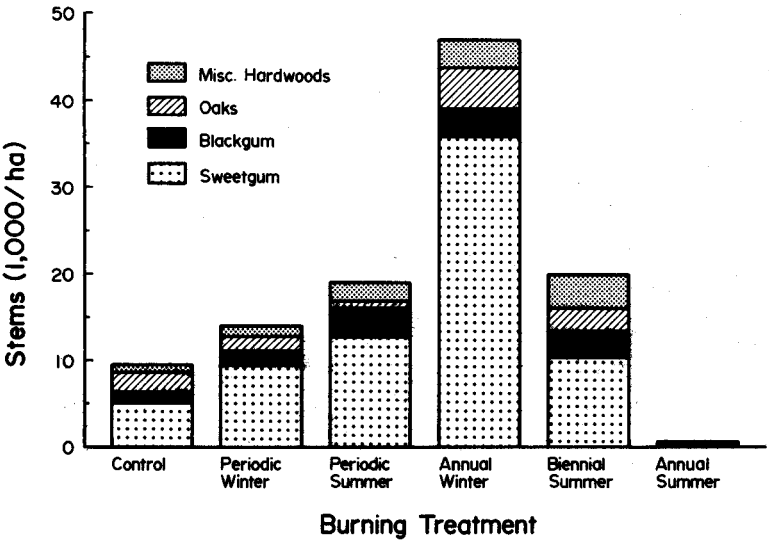


Figure 3.--Number of understory hardwoods less than 2.5 cm d.b.h. after 30 years of prescribed burning by treatment and species group.

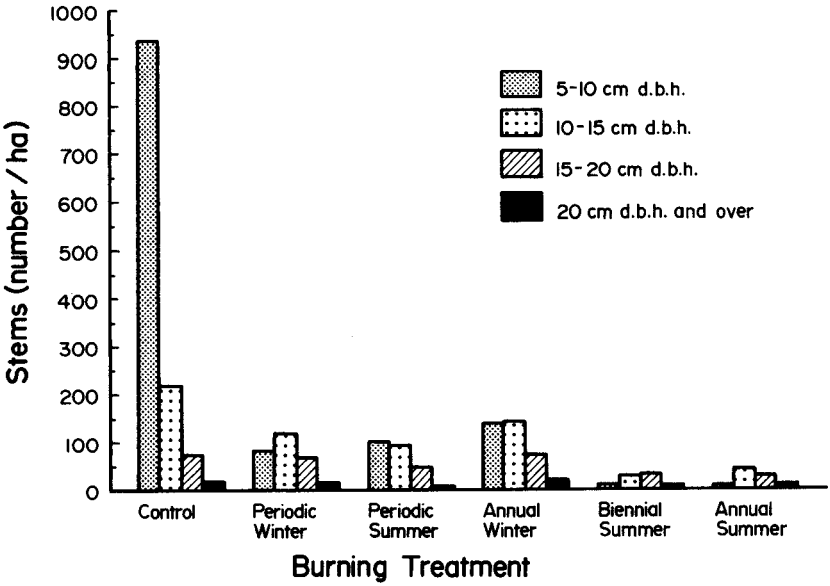


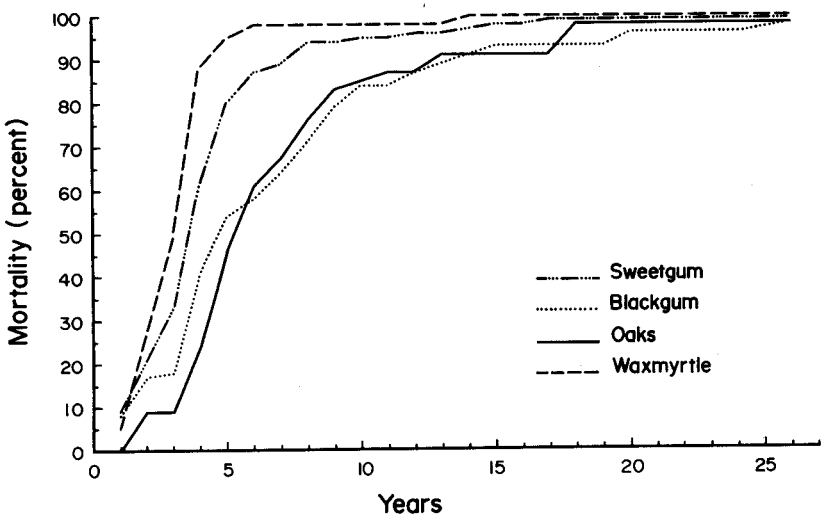
Figure 4.--Diameter distribution of all understory hardwoods over 5 cm d.b.h. by burning treatment after 30 years of prescribed burning.

The number of stems in all diameter classes over 5 cm d.b.h. was reduced by all burning treatments (fig. 4). Control plots had over 900 stems per ha between 5 and 10 cm d.b.h., compared with 140 or less in all burned plots after 30 years of treatment. The reduction in numbers is less obvious in larger diameter classes. Control plots had 220 stems per ha 10 to 15 cm d.b.h., compared with 145 or less in burned plots. Trees in this size class were tall enough and had sufficient bark thickness to survive most low intensity burns. However, localized hotspots of sufficient intensity to kill these larger trees occur occasionally. For hardwoods over 15 cm d.b.h., there are no obvious differences in stem numbers between control plots and plots subjected to winter burning. Winter prescribed burns rarely produced lethal temperatures for the cambium or buds of these large trees. A few trees in these larger size classes have been killed during summer burns when hotspots are more likely to occur.

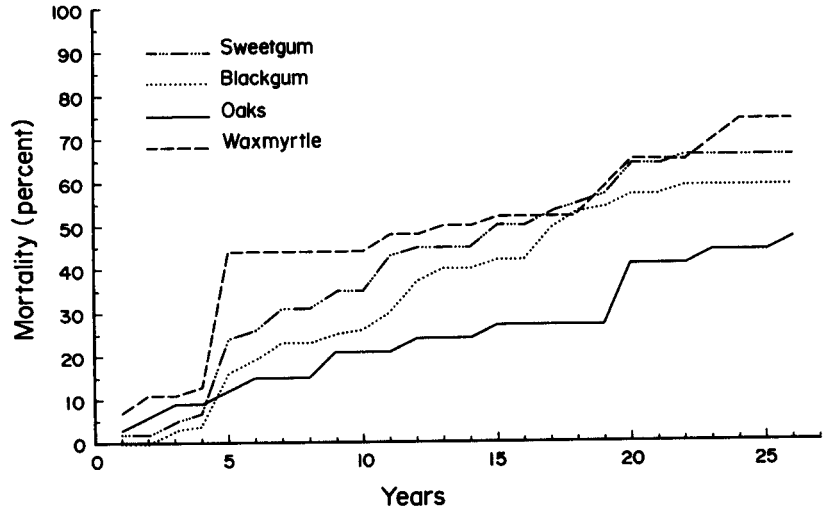
Biennial summer burning was added to the study to provide a comparison with annual summer burning in a study of the survival of the root systems of four hardwood species. Individual trees were observed repeatedly to determine the number of annual or biennial summer burns required to kill their root systems. With annual summer burning (fig. 5A), mortality was fairly rapid for sweetgum and waxmyrtle, nearly 100 percent within 8 years. Oaks and blackgum were more difficult to kill with annual summer fires. Biennial summer burning (fig. 5B) was less effective in killing root systems of all species tested. After 26 years (13 burns), mortality among the oak species remained less than 50 percent. With biennial burning, root systems have an entire growing season to recover. Apparently, that time is sufficient for carbohydrate reserves to accumulate enough to allow some resistance to fire.

Shrubs have also been affected by season and frequency of burning (fig. 6). Shrub density was increased by both periodic burning treatments due to increased sprouting of waxmyrtle and pepperbush. Shrubs are less resistant to frequent burning than understory hardwoods. Only a few stems of blueberry and sumac remain in plots burned annually in summer.

Total crown coverage for all types of understory plants is shown for each treatment in figure 7. Control plots are covered mostly by shrubs with some grasses, vines, and hardwoods. Total coverage is increased by periodic burns due to increased sprouting of hardwoods after winter and summer burns and increased abundance of vines after winter burns. Total coverage after annual winter burns is similar to that in control plots, but species composition has changed. Burning has greatly reduced the shrub component, which has been replaced by grasses and forbs. After biennial summer burns, coverage by shrubs, vines, and hardwoods is similar to that after annual winter burns. However, grasses and forbs are more common,



A. Annual Summer Burn



B. Biennial Summer Burn

Figure 5.--Cumulative mortality of hardwood roots over 26 years of prescribed burning.

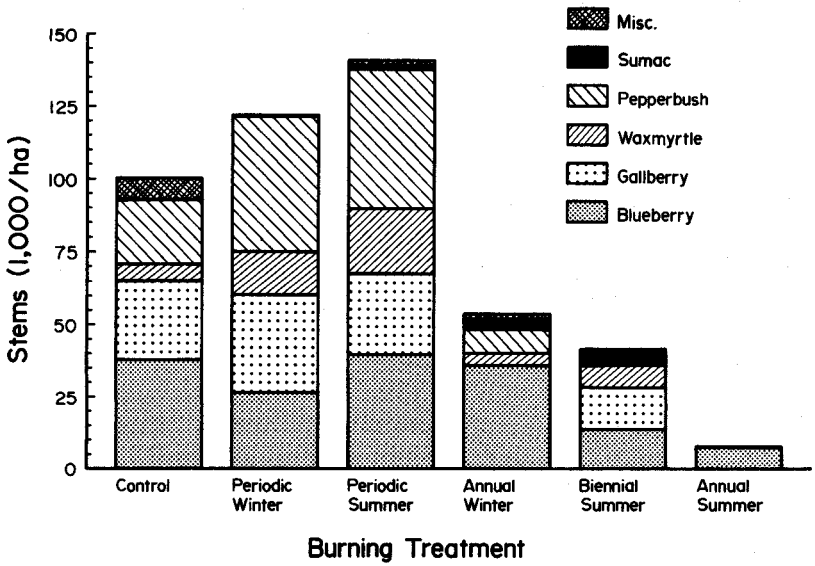


Figure 6.--Number of shrubs by species and treatment after 30 years of prescribed burning.

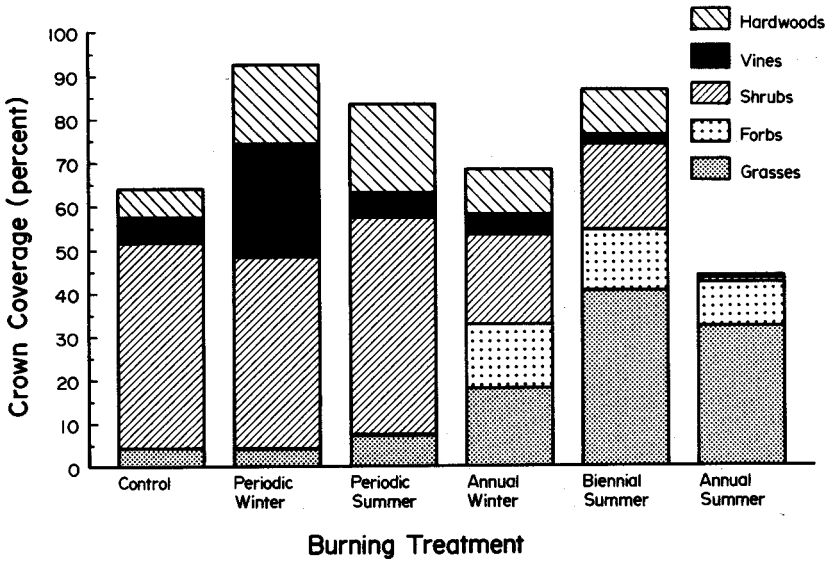


Figure 7.--Percent crown coverage of all understory plants less than 1.5 m tall after 30 years of prescribed burning.

providing an increase in total coverage. In annual summer burn plots, almost all of the shrubs, vines, and hardwoods that were dominant in 1946 have been replaced by grasses and forbs.

Soil Properties

Fear of soil damage resulting from consumption of the forest litter layer has long been a concern of foresters. However, evidence indicates that low-intensity prescribed burns do not adversely affect soils. Ralston and Hatchell (1971) concluded that large changes in soil physical properties can only be expected from wildfires of high intensity. Low-intensity prescribed burns leave a protective mat of unburned litter on the forest floor. This mat reduces raindrop impact and minimizes soil erosion and plugging of soil macropores.

McKee (1982) studied effects of repeated prescribed burning on several soil properties in the Santee fire plots. The various burning treatments caused significant changes to the amount of organic matter in the forest floor and top 10 cm of mineral floor (fig. 8). All burning treatments reduced the depth of the litter layer, thus significantly reducing the amount of organic matter on the forest floor. In the top 10 cm of mineral soil, a different pattern was observed. Periodic winter or summer burns had little effect on soil organic matter content. Although not statistically different, average soil organic matter levels were higher on plots burned annually in winter and summer than those on control plots. Probable causes are a greater abundance of fibrous-rooted grasses and forbs on frequently burned plots (fig. 7), plus accumulation of charred material in the soil profile.

Total nitrogen content of the forest floor was significantly reduced by all burning treatments due to reduced accumulation of litter (fig. 9). However, nitrogen content of mineral

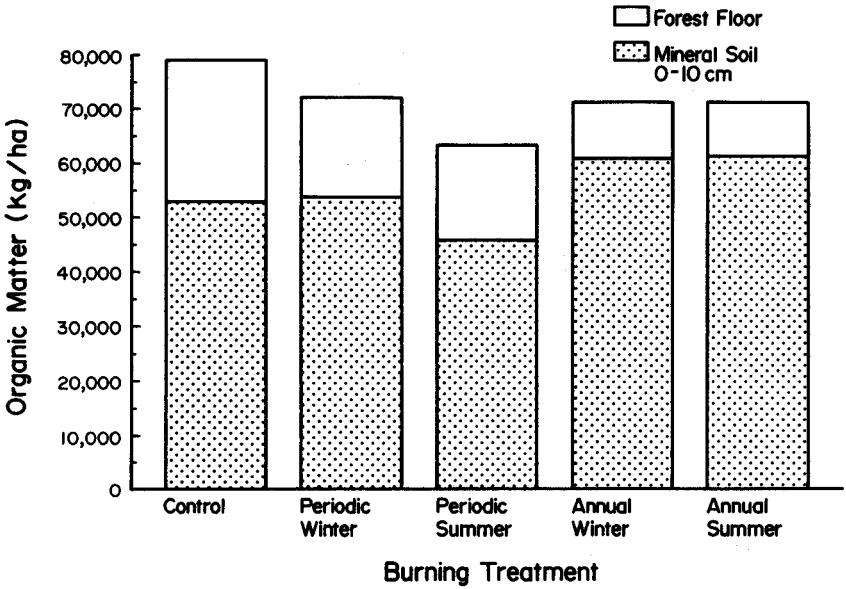


Figure 8.--Organic matter in the forest floor and mineral soil after 30 years of prescribed burning.

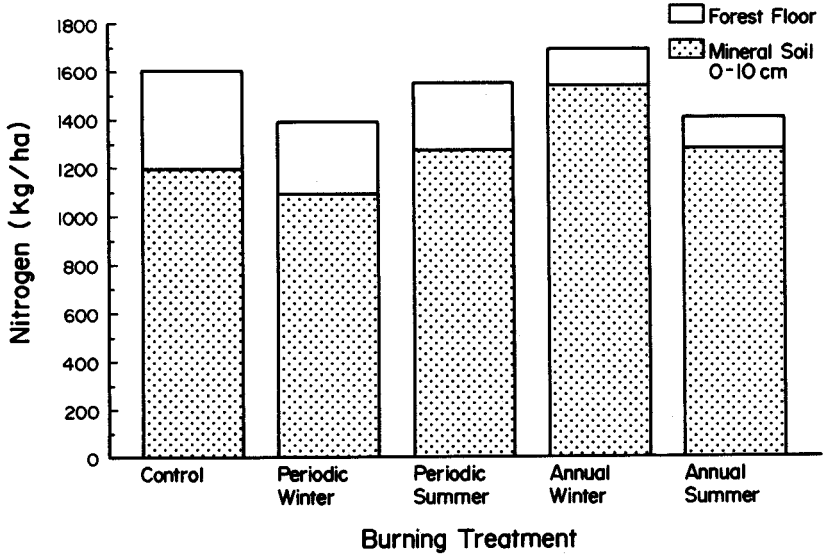


Figure 9.--Total nitrogen in the forest floor and mineral soil after 30 years of prescribed burning.

soil was not reduced by periodic burning and was increased slightly by annual burning in winter or summer. Wells (1971) showed nitrogen losses of 112 kg per ha through volatilization during prescribed fires. However, nitrogen was quickly replaced in the soil through nitrogen fixation. Annual burning allows establishment of herbaceous leguminous plants, which have nodules on their roots containing nitrogen-fixing species of Rhizobium bacteria. Fixed nitrogen

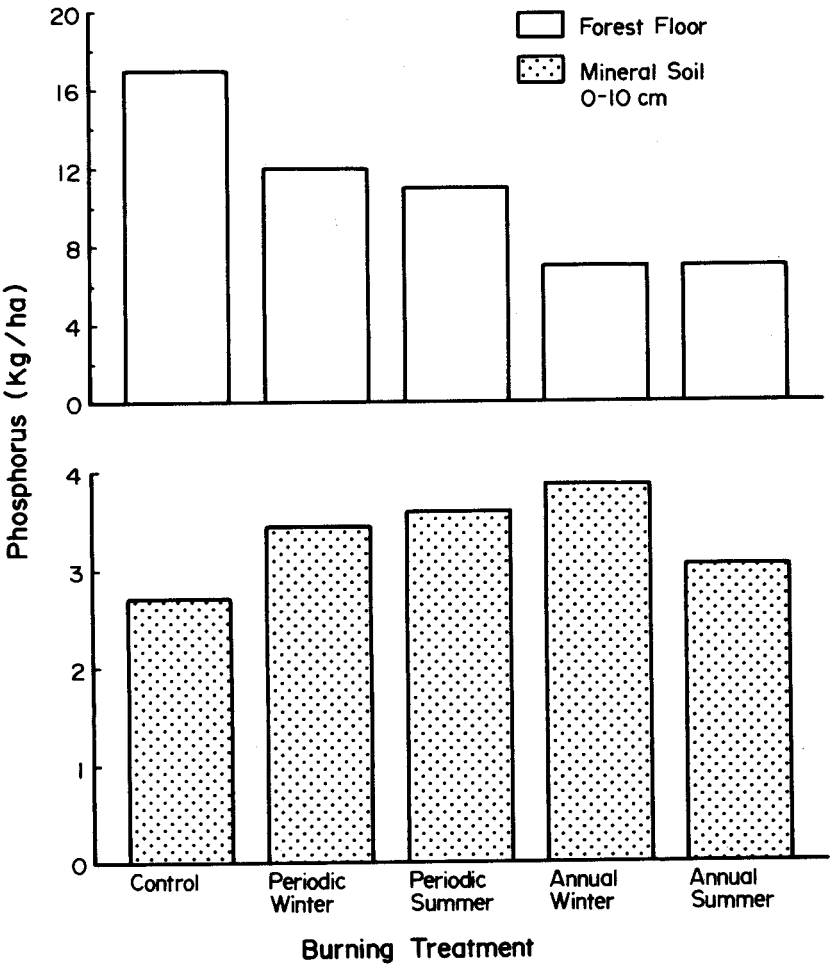


Figure 10.--Total phosphorus in the forest floor and available phosphorus in the top 10 cm of mineral soil after 30 years of prescribed burning.

becomes incorporated into the top layer of soil, thus improving soil fertility. Jorgensen and Wells (1971) noted that annual winter and summer burning also appeared to increase nitrogen fixation by nonsymbiotic bacteria. Numbers of waxmyrtle, which has a symbiotic relationship with a nitrogen-fixing actinomycete (Frankia), were increased by periodic burning in summer or winter (fig. 6), but nitrogen content of the mineral soil was unchanged.

All burning treatments reduced total phosphorus content of the forest floor (fig. 10) but increased available phosphorus content in the top 10 cm of mineral soil. This finding is significant for phosphorus-deficient Coastal Plain soils. Increases in available soil phosphorus created by frequent burning may increase vigor and growth of crop trees.

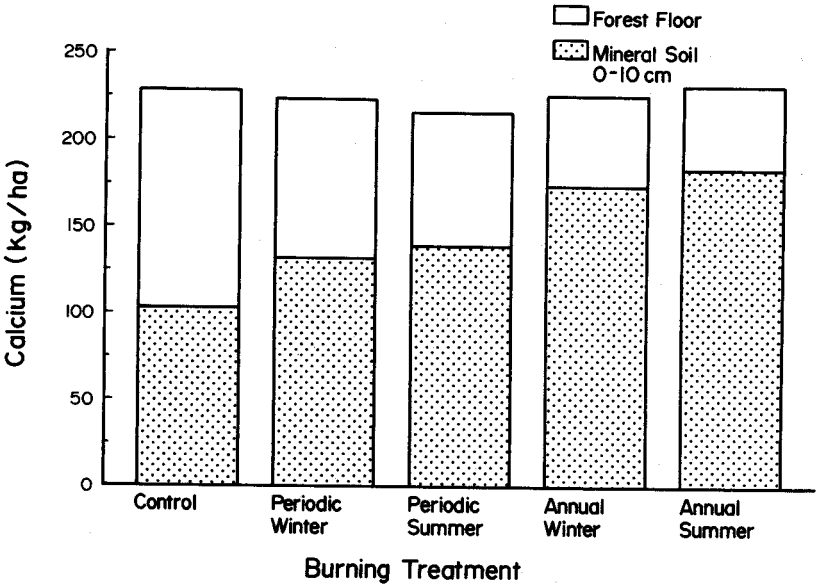


Figure 11.--Exchangeable calcium in the forest floor and mineral soil after 30 years of prescribed burning.

Burning did not change the calcium content in the combined forest floor and top 10 cm of mineral soil (fig. 11). However, there was a

transfer of calcium from the forest floor to the mineral soil. Calcium is immobilized in the forest floor and is made available to plants slowly through mineralization reactions. Burning rapidly releases calcium from the forest floor, allowing it to leach into the mineral soil and become more available for plant nutrition.

McKee (1982) studied effects of prescribed burning on other nutrients such as magnesium and potassium. In all cases, prescribed burning had no adverse effects on nutrient contents of soils in the Santee fire plots. With some treatments, particularly annual burning, soil fertility was increased. The litter layer was partially removed by all burning treatments, but never entirely. Even though an unknown quantity of nutrients was lost to the atmosphere during burning, the major effects of fire were apparently a stimulation of nitrogen fixation and a redistribution of nutrients from the understory and forest floor to mineral soil.

Tree Growth

Since many variables control tree growth, results of different studies on the effects of prescribed burning on growth are often conflicting. In general, fire is not recommended where pines are less than 3.5 m tall. Shorter trees are susceptible to needle scorch and stem damage, which can retard growth or kill the tree. As pines become taller, their buds and needles are protected from the heat of the fire and their bark is generally thick enough to insulate the stem. If prescribed fires control competing understory plants or improve soil fertility, growth rates of overstory pines may be increased.

The Santee fire plots were designed to study effects on understory vegetation with little consideration to tree growth. Detailed records

of the number and size of trees were not kept throughout the 41-year history of the study. Because of the unique long-term nature of the study, efforts were begun in 1984 to examine tree growth rates in relation to burning treatments. If repeated prescribed burning affected growth rates, changes should be visible in tree growth rings. Increment cores (cylindrical sections drilled from tree stems) were extracted at breast height from all trees in all plots. Estimates of stem diameters in past years were determined by subtracting the width of each annual growth ring (measured from increment cores) from the present diameter of the tree. Estimates of diameters were used to calculate stand basal area (a measure of stand density defined as the sum of the cross-sectional area of all trees at 1.37 m above ground).

Basal area per hectare for each burning treatment throughout the study is shown in figure 12. As tree stems grow, stand basal area increases until one or more trees die. Since records of tree mortality were not kept, figure 12 represents

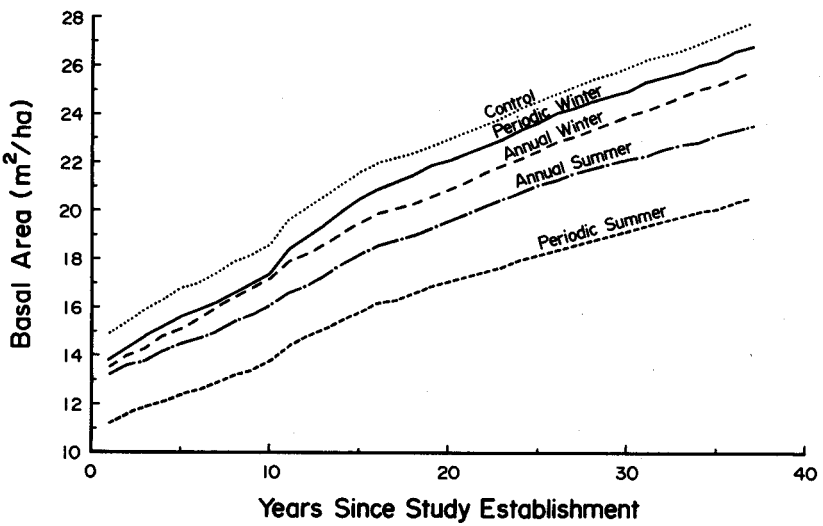


Figure 12.--Cumulative basal area of trees surviving from 1946 through 1984 by burning treatment.

the basal area of only those trees that survived until 1984. Differences in the height of these curves represent differences in numbers and sizes of trees in treatment plots today. Differences in tree sizes and numbers are due to chance plot selection rather than treatment effects. If burning treatments alter tree growth rates, the effect would be shown as differences in the slopes of these curves rather than as differences in the relative heights.

All curves in figure 12 are generally parallel, indicating that burning has not affected diameter growth rates. When growth rates were subjected to analysis of variance, the statistical test indicated that the differences between treatments were not significant. Therefore, none of the burning treatments increased or decreased rates of diameter growth on overstory pines of the Santee fire plots.

Height growth was studied with a standard stem-analysis procedure on felled sample trees. This procedure provides estimates of height growth during each year of a tree's life. Mean tree height for each treatment throughout the lives of these stands is shown in figure 13. Curves are very close together, indicating that trees in various treatment plots have had similar height growth patterns. During the past 30 years, trees in annual winter and summer burn plots appear to have slightly reduced rates of growth. These differences were not significant, however, when compared by analysis of variance.

The lack of statistically significant differences in diameter and height growth was unexpected. We expected that control of competing vegetation and increased soil fertility resulting from prescribed burning would improve growth rates. However, overstory pines averaged 40 years old at the beginning of the study and were probably too old to respond by the time these site changes reached significant levels. Even though McKee (1982) showed increases in

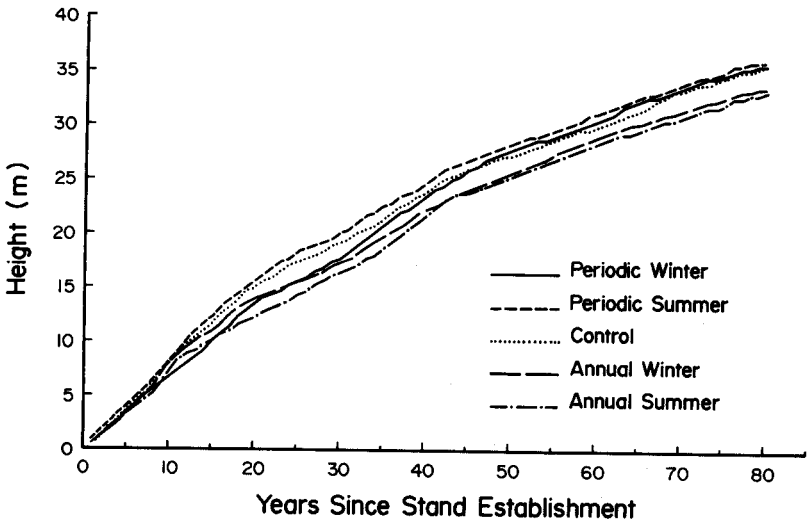


Figure 13.--Mean height of sampled trees by burning treatment from 1905 through 1984.

phosphorus and calcium availability, no fertilization studies in the Coastal Plain have shown positive responses to these elements in trees of this age. In addition, soil moisture is rarely limiting to pine growth on these poorly drained Coastal Plain sites, even when competing vegetation is not controlled.

Conclusions

The Santee fire plots provide an unusual opportunity to observe changes to a southern pine forest ecosystem caused by repeated prescribed burning over a span of over four decades. These study plots show that prescribed burning can effectively control understory vegetation. The degree of control is dependent upon the season and frequency of burning and the size and species of vegetation. Understory hardwoods over 10 to 15 cm d.b.h. were not severely damaged by low-intensity burns and therefore cannot be controlled by low-intensity burning, even on an annual basis. Occasional

hotspots, particularly during summer burns, killed a few of these large hardwoods. Number of stems 5 to 10 cm d.b.h. was dramatically reduced by all burning treatments. Stems of this size were susceptible to top-kill, and burning was frequent enough to prevent sprout growth into this size class. Because of sprouting from surviving rootstocks, number of hardwood stems less than 2.5 cm d.b.h. was increased by all burning treatments except annual summer burning. Annual summer burning eventually killed roots of all understory hardwoods, leaving only grasses and forbs on the forest floor. The roots of oaks had lower mortality rates than those of other understory species--a competitive advantage under a regime of frequent burning.

Removal of understory vegetation by prescribed fires, particularly annual burning, is of practical significance. These fires create stands that have an open "parklike" appearance. Without the dense brush, which is typical of unburned stands of the Southeast, forests are more accessible to people, wildlife, and equipment. Costs of cultural treatments to the stand, such as fertilization and thinning, are reduced, large animals are more free to move within the stand, and woody stems are replaced by more palatable forbs and succulent sprouts. Since pine seedlings have reduced competition for growing space, the chances for pine regeneration after harvest are improved. The greatest benefit of controlling understory vegetation is probably protection from wildfire by reducing fuel concentrations. If a wildfire should occur, its intensity would be much lower in an area that was frequently burned than in an area with a heavy fuel load. As a result, there is less damage to forest resources and fire suppression is easier.

Even though the Santee fire plots have been burned many times, no adverse changes to the chemical or physical properties of these sand and silt loam Coastal Plain soils have been

observed. Soil productivity may have been improved by increases in available phosphorus, exchangeable calcium, and organic matter in the mineral soil. Increased phosphorus availability is particularly important because most Coastal Plain soils are deficient in phosphorus. Total nitrogen in the soil was not reduced by burning. It increased slightly after annual winter and summer burning due to increased abundance of nitrogen-fixing legumes and forbs. All burning treatments reduced the thickness of the forest floor but rarely exposed mineral soil.

Limited records of the number and size of overstory pines on each plot over the duration of the study made an analysis of the effects of prescribed burning on tree growth difficult. Increment core and stem analysis of trees living in 1984 showed no significant changes in diameter or height growth that could be attributed to prescribed burning. This result was somewhat unexpected because reduced competition from understory vegetation and increased soil fertility should enhance growth. However, these changes occurred gradually over time. Since the overstory pines were approximately 40 years old when the study began, they may have been too old to benefit by the time these site changes reached significant levels. Although pine growth was not increased by burning, the fact that growth rates were not decreased is quite important. Several studies have shown retarded growth rates in young stands when fires were of sufficient intensity to scorch needles or damage stems. The chance of this occurring on the Santee fire plots was high because of the large number of fires conducted, particularly during the early years of the study when understory vegetation provided abundant fuels. When fires are conducted with proper care, damage to the stand can be avoided. Careful burning allows the forest manager to achieve many benefits at minimal cost.

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