# EFFECTS OF PRESCRIBED BURNING ON SOIL CHEMICAL PROPERTIES AND NUTRIENT AVAILABILITY

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Understanding the effects of prescribed burning on soil properties is important in forestry applications. If burning has no detrimental effect on soil, it can be used for fuel reduction and hardwood control. However, if burning does have an adverse influence on soils, that adversity could be a major consideration in not using fire. Of course, we should initially recognize that there is no one answer to the problem of the effects of burning on soil chemical properties, because the kind of soil, climate, vegetation, and intensity of burn will all have a bearing on the final decision.

Both burning and natural biological decomposition release mineral elements from organic matter to the soil. In biological decomposition, nutrient release is slow and steady, with most of the released nutrients taken up by plants on the site. In some instances, the annual release may be quite small; for example, a young pine stand still accumulating a forest floor. As a result of a burn, nutrients are released rapidly and much of the soluble mineral material and some fine organic residues may move down the profile.

After burning, the fate and movement of the released elements through the profile depend on the characteristics of the soils' organic and mineral layers and the nutrient uptake by plants on the site. When only the upper part of the forest floor is burned, the unburned residue has the capacity to adsorb or utilize biologically a portion of the soluble elements. Some materials may be lost by runoff, but most reach the mineral soil where they can accumulate near the surface, leach deeper into the profile, be used by plants, or, in soils with excessive drainage,



USDA Forest Service. 1971. Prescribed burning symposium proceedings. Southeast. Forest Expt. Station. pp. 86-97.

enter the ground water. The influence of burning on soil organic matter and nitrogen are of particular importance because these two factors have a strong influence on soil fertility and productivity.

A 20-year prescribed burn study in the Coastal Plain.--We have recently completed a report on a study of 20 years of prescribed burning in the South Carolina Coastal Plain.[1] Interim results after 10 years of burning were reported by Metz (9). The longest and most complete of any in the South, this study is the main source of information for this paper. Treatments were check or no burning, periodic winter burn, periodic summer burn, annual winter burn, and annual summer burn. There were four burns in 20 years for the periodic treatments. There were five replications, three on the Santee and two on the Westvaco Forest. Treatment effects on nutrient concentrations were tested by chemical analyses and on nutrient uptake by growing loblolly pine seedlings in pots of soil.

The soils were mainly Coxville very fine sandy loam, but several other series were also found on the plots. All soils were poorly or very poorly drained, nearly level, and very acid. The humus type was a duff mull and the A horizon was about 6 inches thick. The soils in this study are common in the flatwoods of the lower Coastal Plain.

Organic matter.--The most obvious effect of burning on the soil is the reduction in the forest floor. Even in the annually burned plots, charred branches and needles covered the mineral soil. Where periodic fires had been used, except for the first year or two after burning, there was little visible change in the forest floor.

An accurate measure of the effect of burn severity on the forest floor is weight loss. Ranking the treatments on a weight-loss scale, from the most severe to the least severe, showed the annual summer burn the most severe, followed by annual winter, periodic summer, periodic winter, and check treatments (fig. 1). There was no statistically significant difference in the forest floor between the check and the periodic winter burn treatments, but all others differed significantly. After 20 years, annual summer and annual winter burns reduced the forest floor to 7,000 and 13,000 lb. per acre, respectively.

Forest floor samples collected immediately after a periodic winter burn showed a loss of 6,500 lb. of the 24,000 lb. per acre of the forest floor initially present. After 20 years and four burns of this type, however, the average forest floor, burned periodically in the winter, was reduced by only 2,000 lb. per acre. Periodic summer burns consumed more organic matter, yet after four such burns, the forest floor decreased by only 8,000 lb. per acre.

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[1] Wells, Carol G., and Hatchell, Glyndon E. Some effects of prescribed burning on coastal plain forest soil. (In preparation for Forest Sci. Monogr.)

The loss for a single winter burn is comparable to the loss found by Brender and Cooper (1) who reported fuel consumption of 4,800 to 6,300 lb. per acre in a loblolly pine stand in the Georgia Piedmont.

Several studies across the South have given comparable results over a shorter span of time. In Arkansas (10), 10 annual burns decreased the forest floor from 11,000 to 4,000 lb. per acre. On a wet site in the Virginia Coastal Plain (11), four annual winter and three summer burns removed 14 of the 36 tons of forest floor. These reports and our study show that prescribed burning does not remove all of the forest floor, and that under some conditions, a single burn may remove only a small percentage of it.

Organic matter in the mineral soil in burned plots increased over the 20-year period. For the 0- to 2-inch depth, there was about 30 percent more organic matter in the annually burned plots than in the check plots, but there was no difference between treatments at the 2- to 4-inch depth.

A comparison of organic matter in the 0- to 2-inch depth at the end of the 10th and 20th years shows that most of the increase in organic matter occurred in the first 10 years. The increase in organic matter during the first 10 years was a result of burning the forest floor that had accumulated before the treatments began, whereas annual litterfall was the only fuel during the second 10 years and the established soil-organic matter level remained near the same. When the influence of fire on organic matter in both the forest floor and the 0 to 4 inches of mineral soil was taken into account, the principal effect of burning was the redistribution of the organic matter in the profile, and not in any reduction.

Nitrogen.--In the South Carolina study area, as in other regions, nitrogen is highly correlated with organic matter. When the forest floor was destroyed by burning, in all treatments except the periodic winter burn, nitrogen significantly decreased in the same order as burn severity increased. As nitrogen decreased in the forest floor, however, it was accumulated at about the same rate in the 0- to 2-inch layer of mineral soil. Again, as with the increase of organic matter in the 0- to 2-inch layer, most of the nitrogen was accumulated during the first 10 years of burning.

Sampling before and after a periodic winter burn showed that the single burn caused a loss of 100 lb. of nitrogen per acre. Four of these burns in 20 years would have volatilized 400 lb. of nitrogen. More severe burning over the 20-year study period would have destroyed a larger portion of the forest floor and produced even greater nitrogen losses; yet when total nitrogen was summed through the 4 inches of mineral soil, losses were not detectable.

Two annual burned plots showed nitrogen increases of 500 lb. and 900 lb. per acre during the second 10 years of the study. Investigation indicated greater nitrogen-fixing activity on annual burned plots than on control plots or unburned areas surrounding the plots (5). The plots with the greatest nitrogen accumulation were the wettest and this combination, together with the effects of burning, could have stimulated nitrogen fixation by anaerobic, nonsymbiotic microorganisms. Other workers have also suggested increased nitrogen fixation after burning (8, 14).

Phosphorus, potassium, calcium, and magnesium.--At the end of 20 years of burning treatments, phosphorus was not significantly changed in the 0- to 2- or 2- to 4-inch depths; but when summed for the 0 to 4 inches, there was significantly more phosphorus in the annual winter burn plots than in the check plots (table 1). Potassium was not influenced by burning. Calcium and magnesium increased significantly in the 0- to 2-inch depth but not in the 2- to 4-inch depth..

Table 1.--Weight of phosphorus, potassium, calcium, and magnesium in the forest floor (F.F.), 0 to 2 and 2 to 4 inches of mineral soil

| Layer | Annual summer | Annual winter | Periodic summer | Periodic winter | Check |
|---|---|---|---|---|---|
| | | | lb. per acre | | |
| PHOSPHORUS[a] | | | | | |
| F.F. | 3.6 | 8.0 | 10.4 | 14.8 | 16.2 |
| 0 to 2 | 3.7 | 4.1 | 3.3 | 2.9 | 2.9 |
| 2 to 4 | 1.5 | 1.8 | 1.6 | 1.4 | 1.4 |
| 0 to 4 | 5.2 | 5.9 | 4.9 | 4.3 | 4.3 |
| POTASSIUM[a] | | | | | |
| F.F. | 5.4 | 13.1 | 13.8 | 23.7 | 24.7 |
| 0 to 2 | 16.6 | 18.9 | 14.8 | 15.5 | 15.6 |
| 2 to 4 | 9.0 | 11.3 | 9.8 | 8.4 | 8.9 |
| 0 to 4 | 25.6 | 30.2 | 24.6 | 23.9 | 24.5 |
| CALCIUM[a] | | | | | |
| F.F. | 40 | 77 | 124 | 134 | 140 |
| 0 to 2 | 142 | 74 | 101 | 51 | 29 |
| 2 to 4 | 55 | 27 | 72 | 23 | 16 |
| 0 to 4 | 197 | 101 | 173 | 74 | 45 |
| MAGNESIUM[a] | | | | | |
| F.F. | 6.8 | 13.9 | 19.1 | 24.3 | 27.5 |
| 0 to 2 | 21.9 | 16.8 | 16.5 | 11.1 | 9.5 |
| 2 to 4 | 13.4 | 10.0 | 10.7 | 6.6 | 6.6 |
| 0 to 4 | 35.3 | 26.8 | 27.2 | 17.7 | 16.1 |

[a] Quantities are not comparable between forest floor and 4 inches of mineral soil because only extractable quantities were measured in the mineral soil and total analysis was made of the forest floor.

A comparison of the amount of phosphorus, potassium, calcium, and magnesium in the forest floor of burned and check plots shows that treatment produced relatively small differences. The most severe treatment, annual summer burning, moved only 13, 20, 100, and 21 lb. per acre of phosphorus, potassium, calcium, and magnesium, respectively, from the forest floor to the mineral soil over the 20-year period. These quantities had a very small effect on nutrients in the mineral soil when considered on an annual basis. Therefore, the soils are still low in exchangeable cations and available phosphorus.

At the end of 10 years, both annual treatments contained significantly more phosphorus in the 0- to 2-inch layer than the check and the periodic winter treatments, and the annual summer fire treatment was greater than the periodic summer fire treatment (9). There was significantly more magnesium in the 0- to 2-inch soil depth of the annual summer fire treatment than in the periodic treatment or check. Calcium showed an increase from burning, but the effect was statistically nonsignificant.

The effect of burning on mineral elements has, under some conditions, been too small to be significant (10, 12, 16). In general, burning has increased exchangeable calcium and magnesium (2, 3, 4, 7, 15).

The literature has not always shown the quantity and content of the burned material. For this reason, it is not now possible to quantitatively compare and develop methods to predict the results of a burning treatment. However, for mineral elements, basic principles can be applied to quantities of forest floor, soil chemical properties, texture, and drainage. For example, a study in Arkansas (10) may be compared with the one in South Carolina.

In Arkansas, in a loblolly-shortleaf pine stand with 11,000 lb. of forest floor per acre, 10 years of biennial and annual burning on imperfectly drained Grenada and Calloway silt loam had no effect on pH and nutrients in the 0- to 2- and 2- to 4-inch depths of mineral soil. In the South Carolina study, the soil was poorly to very poorly drained, had 16,000 lb. of forest floor per acre, and 10 years of burning increased the pH, phosphorus, calcium, and magnesium in the 0 to 2 inches of mineral soil. Annual burns decreased the forest floor to about the same amount in both studies. Differences in results could be attributed to soil chemical properties, drainage, and the amount of forest floor burned in the two studies. Exchangeable calcium and magnesium in the 0- to 2-inch depth of the Arkansas soil were 900 and 180 p.p.m. compared to 174 and 52 p.p.m. in the South Carolina soil. The amounts of these elements released by burning would be very small in comparison with the natural amounts in the Arkansas soil, but they would be important for the South Carolina soil. There was a greater possibility for leaching of elements through the surface 4 inches of the Arkansas soil, although leaching did not appear to be a factor.

Soil pH.--In this very acid, poorly drained soil, 20 years of burning decreased the acidity from pH 3.5 to 4.0 in the F and H horizons, and from 4.2 to 4.6 in the 0 to 2 inches of mineral soil.

There was no significant change in the 2 to 4 inches of mineral soil. Most of the change in pH occurred during the first 10 years of burning. The decrease in acidity of the surface layer was the result of ash residues which contained basic elements. The magnitude of change in pH depends on the amount of ash, the quantity of potassium, calcium, and magnesium in the ash, and the texture and organic-matter content of the soil. Ash produced by burning will increase pH more and to a greater depth in an organic-matter deficient sandy soil that has a low cation exchange capacity than it will in a soil with more organic matter and clay and a higher cation exchange capacity. In addition to the release of basic ions, destroying organic matter by burning reduces the formation of organic acids. These acids, formed during biological decomposition, are in part responsibile for soil acidity.

Nutrient availability by pot experiments.--Nutrient availability is often evaluated by pot experiments. The lack of knowledge about the form of nitrogen residues after burning makes this type of experiment particularly adaptable to nitrogen investigations. On ponderosa pine in the Coastal Range of northern California, Vlamis et al. (13) found burning treatments increased the nitrogen- and phosphorus-supplying power of the soil to indicator lettuce plants. The increase was considerably greater when tests were made 1 year after burning than it was after 2 years. In a second pot experiment, Vlamis and Gowans (14) found that brush burning increased the nitrogen, phosphorus, and sulfur supply to plants on soils acutely deficient in these elements. Wahlenberg (15) reported an increase in available nitrogen, exchangeable calcium, and organic matter after burning; and in greenhouse tests, slash pine grew better on the burned soil. Responses to the mineral elements released in burning are expected when supplies of the elements are limited. In contrast to this increased growth on the burned soil, spruce seedlings in pots of soils from repeatedly burned hardwood stands had poorer growth (6).

In South Carolina, two experiments to study seedling growth and nutrient uptake were conducted with soil from the burning treatment plots. For a test of seedling growth on undisturbed soil, cores 4½ inches in diameter and 5 inches deep were taken from the A horizon. The forest floor was left intact and the cores were placed in ½-gal. pots. In another study, six 1-gal. pots were filled with a mixed soil from the 0- to 2-inch mineral layer of each treatment on the Santee Forest. The soil of three pots was covered with a forest floor representative of that treatment, and the remaining three pots were covered with glass wool. After loblolly pine seedlings were grown in the pots for about 6 months, they were measured, removed from the pots, weighed, and analyzed for nutrient content.

Burning treatments had no effect on the growth of plants, but there was a tendency for fire to influence the uptake of some nutrients (table 2). Uptake of nitrogen by the seedlings had a similar pattern in both core and mixed soil pots. Although plants grown in soil from annual summer burns took up 16 to 40 percent less nitrogen than plants grown in soil from periodic winter burn and check treatments, the burning treatment effect on nitrogen uptake was not significant.

Table 2.--Uptake of N and P by seedlings in the cores and mixed soil

| Burning treatment | Cores | Mixed soils: Forest floor | Mixed soils: Glass wool |
|---|---|---|---|
| | mg./pot | | |
| NITROGEN | | | |
| Check | 41 | 93 | 100 |
| Periodic winter | 44 | 103 | 109 |
| Periodic summer | 38 | 89 | 107 |
| Annual winter | 36 | 86 | 86 |
| Annual summer | 28 | 60 | 69 |
| PHOSPHORUS | | | |
| Check | 2.8 | 5.3 | 4.2 |
| Periodic winter | 4.2 | 7.1 | 6.3 |
| Periodic summer | 3.1 | 6.8 | 7.3 |
| Annual winter | 3.5 | 7.8 | 8.2 |
| Annual summer | 2.7 | 6.3 | 7.2 |

Seedling weight and nutrient uptake was greater for the seedlings with glass wool mulch than for those having a forest floor cover. In a similar test of a Piedmont soil with 0.02 percent nitrogen, in contrast to an average of 0.15 percent nitrogen for the Coastal Plain soil, loblolly pine grew much larger with forest floor cover. In the test of Piedmont soil, the forest floor provided about 50 percent of the nitrogen, phosphorus, and potassium for the seedlings (17). Burning the forest floor of low nitrogen soil would affect seedlings much more than in more fertile soil.

Phosphorus and potassium uptake by seedlings grown in soil cores from burned plots was significantly greater than the uptake by seedlings grown in soil from the check, but there was no statistically significant difference due to burning in the mixed soil (table 2). Uptake of calcium, magnesium, zinc, and manganese was not significantly affected by burning. The uptake of nitrogen and phosphorus was highly correlated ($r = 0.70$); nitrogen uptake was affected by phosphorus uptake as indicated by phosphorus deficiency in some plots. To better test the effect of burning treatment on nitrogen uptake, a statistical analysis was made with phosphorus as covariant and nitrogen as the treatment variable. After this adjustment for phosphorus in the mixed soil experiment, the effect of burning treatment on nitrogen uptake was significant at the 10 percent level. The adjusted treatment means of nitrogen uptake followed fire severity with 116 and 66 mg of nitrogen uptake from check and annual summer burn, respectively (table 3).

Table 3.--Calculated uptake and availability percentage of nitrogen for seedlings in the 0 to 2 inches of mixed soil without forest floor

| Burning treatment | Uptake | Available |
|---|---|---|
| | mg./pot | percent |
| Check | 116 | 2.48 |
| Periodic winter | 111 | 2.92 |
| Periodic summer | 103 | 1.97 |
| Annual winter | 76 | 1.82 |
| Annual summer | 66 | 1.74 |

Expressing nitrogen uptake by plants as a percentage of total soil nitrogen is another approach to evaluate nitrogen availability. A comparison of treatments then shows whether burning has produced residual nitrogen which is resistant to biological mineralization. This approach was pursued to investigate nitrogen in the 0 to 2 inches of mineral soil of the mixed soil experiment.

Nitrogen availability percentage was computed as seedling nitrogen uptake per pot divided by total nitrogen in soil x 100. Nitrogen availability percentage was greatest in the periodic winter fire and least in the annual summer fire treatments (table 3). However, the burning treatment effect was not statistically significant.

## SUMMARY AND CONCLUSIONS

Prescribed burning of mature southern pine stands normally leaves some of the forest floor, even when annual burns are applied. Generally, prescribed burning in these stands causes small increases in soil pH, organic matter, nitrogen, phosphorus, and exchangeable calcium and magnesium in the surface 2 or 4 inches of mineral soil. The effect of burning on the change in mineral element status in the soil is related to the amount and content of those elements in the burned organic matter.

In the 20-year South Carolina Coastal Plain study, a single winter burn volatilized 6,500 of the 25,000 lb. of forest floor per acre and 100 of the 300 lb. of nitrogen per acre. Under some conditions, burning may increase nitrogen fixation in the soil and thus compensate for nitrogen loss to the atmosphere.

Pot experiments with soils from burned forests in different locations have shown increased uptake of nitrogen and phosphorus after a single burn. In the 20-year burn study in South Carolina, seedlings grown in pots of soil from burned plots had a greater uptake of phosphorus than did the controls. Annual burn treatments, however, showed tendencies for nitrogen uptake by seedlings to decrease. This suggests that nitrogen accumulated in the upper 2 inches of mineral soil as a result of repeated burning is less available to plants than nitrogen in soil from nonburned plots.

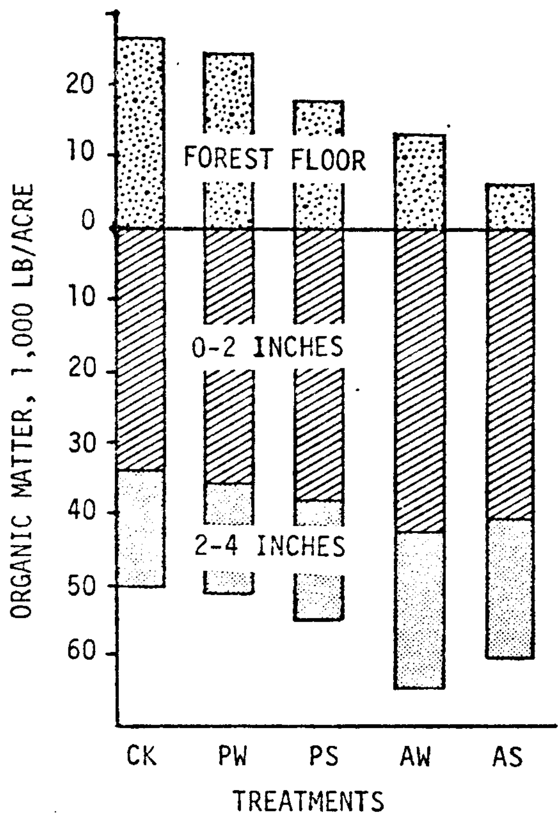


Figure 1.--Organic matter in the forest floor, 0-2, and 2-4 inches of mineral soil for check (CK), periodic winter (PW), periodic summer (PS), annual winter (AW), and annual summer (AS) treatments after 20 years.

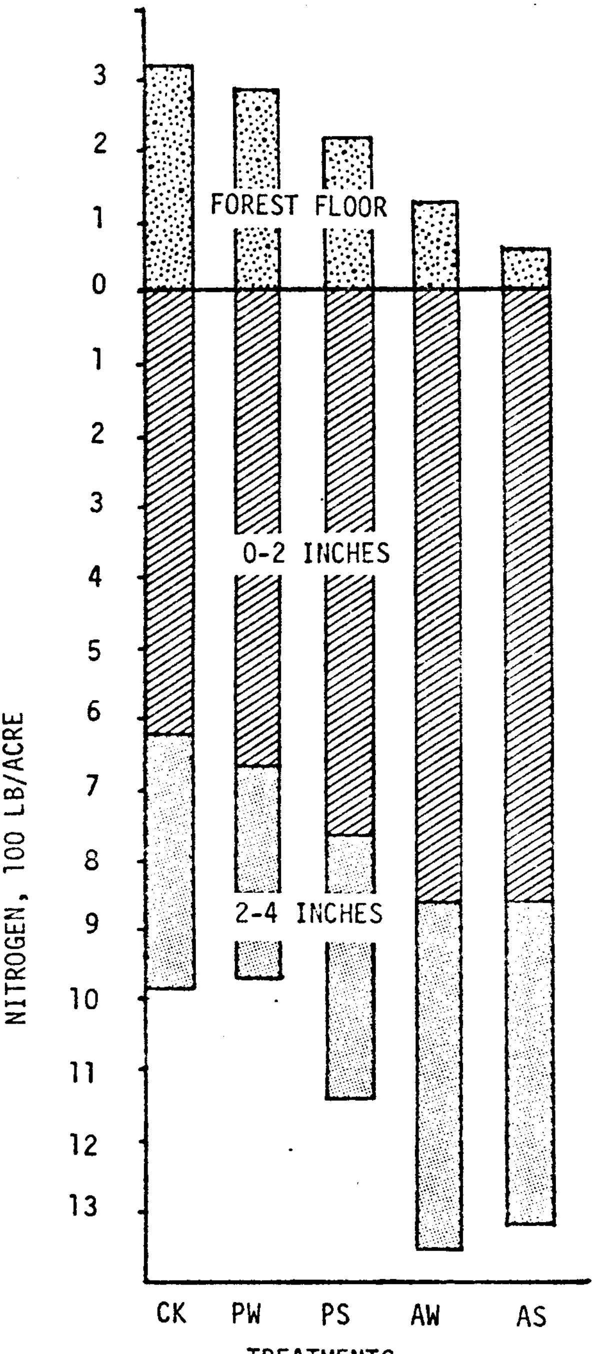


Figure 2.--Nitrogen in the forest floor, 0-2, and 2-4 inches of mineral soil for check (CK), periodic winter (PW), periodic summer (PS), annual winter (AW), and annual summer (AS) treatments after 20 years.

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