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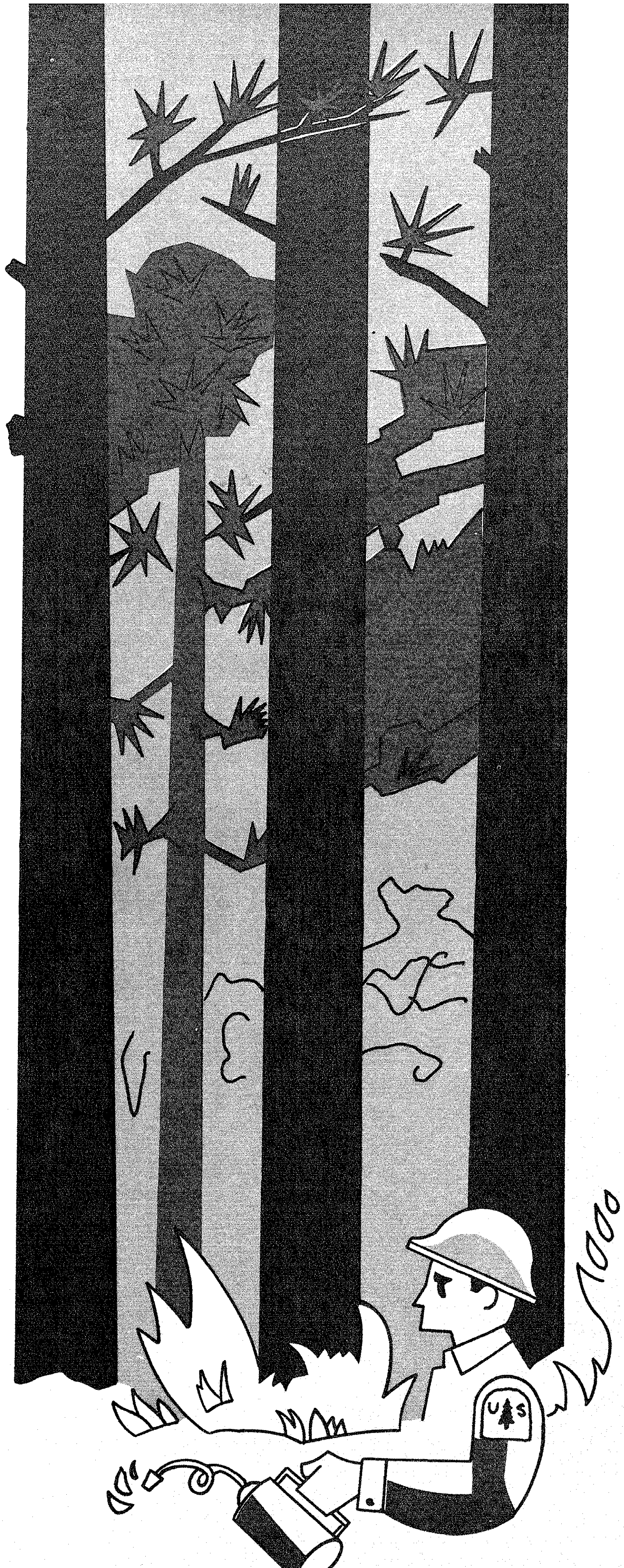

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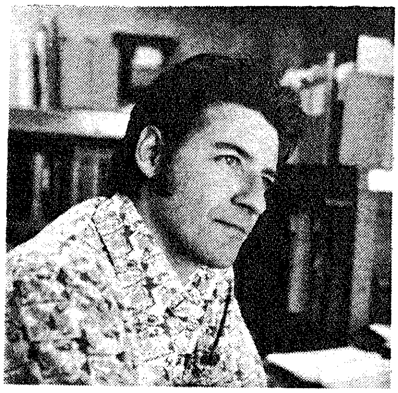

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INFLUENCE ON SOIL PROPERTIES OF PRESCRIBED BURNING UNDER MATURE RED PINE

David H. Alban

Mature red pine (*Pinus resinosa* Ait.) stands usually have a thick accumulation of organic matter on the soil surface and a dense shrub layer. These conditions hinder reproduction. Before the advent of the white man in North America, most red pine stands regenerated following wildfires. The fires reduced shrub vegetation and improved seedbeds by reducing the depth of the forest floors.

Prescribed burning, therefore, is being studied as a potentially useful tool for establishing red pine stands. In Ontario, two consecutive summer burns practically eliminated hazel understory in 80-year-old red pine and white pine (*P. strobus* L.) stands. This produced good regeneration and increased survival of seedlings during the first year (Van Wagner 1963). Similarly, light intensity burns proved effective for understory control in loblolly pine (*P. taeda* L.) stands in southeastern United States (Lotti *et al.* 1960): reproduction was improved and the growth of overstory trees wasn't affected.

The effects of fire on both soils and vegetation have been rather completely reviewed by Burns (1952) and Ahlgren and Ahlgren (1960). Although it is apparent that these changes are complex and depend on a host of factors, certain generalizations seem reasonably consistent: burning has its most pronounced effect on the forest floor in which carbon (C), nitrogen (N), and sulfur (S) are volatilized, and calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and other elements are left as ash. This ash is leached by rains into the mineral soil which increases its base saturation and pH. These changes also may have important effects on the microbial population of the soil (Neal *et al.* 1965). Such soil changes are most pronounced during the first year after burns, but these properties usually revert to their preburn level within a few years. Infiltration rate also frequently decreases when soil pores are filled with fine material and soil animals are killed, which accelerates erosion under some topographic and climatic conditions.

In 1960, we initiated burning experiments to control beaked hazel (*Corylus cornuta*, Marsh) understory in a 90-year-old red pine (*Pinus resinosa* Ait.) stand in Minnesota. Twenty-eight treatment plots were installed; all of which had been thinned to 120 ft^2 of basal area per acre. Four plots were left unburned: the remaining 24 were burned either during the dormant season (spring) or the growing season (summer) at different intervals: annually, biennially, or periodically (6 to 9 years). Each treatment was replicated four times and assigned to the plots using a randomized block design.

Most burns were made between 5 to 15 days after a rain when the moisture content of the forest floor averaged 100 percent (spring) and 40 percent (summer). Backing fires from downwind were used to burn the first 20 foot strip. Headfires, which varied in width from 10 to 20 feet (fig. 1), were used to burn the remainder

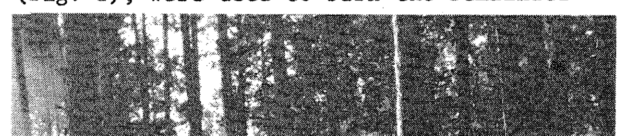

Figure 1.--*Ignition of second burn on a biennial plot.*

of each plot. This minimized charring of stems, scorching of crowns, and kept forest floor weight losses to 50 percent or less.

Burning each treatment during its scheduled year was felt to be more important than getting the hottest possible fire. Prolonged dry periods with their potential for very hot fires were rare and burning only when they occurred would have resulted in very few burns.

The soils have been tentatively classified as belonging to the Cutfoot Soil series (deep, well-drained soils formed from medium and coarse sands that show only weak profile development). The forest floor prior to burning was about 3 inches thick, underlain by loamy sand A1, A2, and B2 horizons approximately 1/2, 4, and 14 inches thick, respectively. Below the B2 horizon, the soils were mainly stratified sands and gravels interspersed with thin lenses of very fine sandy loam. Below 50 inches, calcium carbonate occurs sporadically (tables 1, 2, and 3).

By 1969, the overstory of the study stand was that of a nearly pure 100-year-old red pine stand (mean diameter at breast height, 14.7 in.; mean height, 76 ft; basal area, 141 ft^2/acre; volume, 4,380 ft^3/acre; site index, about 55 ft). Mortality from burning among the overstory trees was low: it totaled 3.5 ft^2 of basal area per acre, about half of which had been on the summer annual burn plots. The periodic annual volume increment of the overstory (average 93 ft^3/acre) had not been significantly affected by the burns.

The understory on the unburned plots was dominated by hazel stems averaging 8-ft

Table 1.--*Distribution of organic matter and nutrients in the forest floor on unburned plots*

Horizon	pH	Ash	Ovendry weight	Organic matter	N	P	K	Ca	Mg
		Percent	- - - - - - - - - -	*Lb/acre*	- - - -	- - - -	- - - -	- - - -	- - - -
L	4.70	6.5	3,810	3,560	40	3.2	14.0	37	4.3
F	4.92	17.7	9,190	7,560	115	8.0	12.3	102	10.2
H	5.02	52.8	26,070	12,300	240	17.8	31.0	201	28.0
Total			39,070	23,420	395	29.0	57.3	340	42.5

Table 2.--*Character of mineral soil on unburned plots*

Depth (in.)	Bulk density[1]	Gravel	Percent of<2mm soil: Clay	Silt	Sand	pH	N	P	Ca	Mg	K	H + Al
	g/cm³	- - - -	*Percent*	- - - -			*Percent*		- - -	*meq/100g*	- - - -	-
0 to 4	1.24	0	5.0	12.3	82.7	5.32	0.059	0.017	1.98	0.40	0.17	0.60
4 to 20	1.41	6.1	4.9	5.8	89.3	5.65	.017	.029	.88	.24	.07	.52
20 to 39	1.48	10.7	4.3	1.1	94.6	5.75	.008	.024	1.63	.44	.09	.12

[1]Estimated from measurements made on similar soils in nearby areas and assumed to be the same on burned and unburned areas.

Table 3.--*Understory nutrient composition and weights on unburned plots*[1]

Nutrient	Herbs		Shrub leaves		Shrub stems		Total weight
	Percent	*Lb/acre*	*Percent*	*Lb/acre*	*Percent*	*Lb/acre*	*Lb/acre*
N	1.85	4.4	1.64	3.8	0.44	5.6	13.8
P	.25	.6	.24	.6	.06	.8	2.0
K	3.00	7.2	1.14	2.7	.25	3.2	13.1
Ca	.73	1.7	2.28	5.3	.80	10.2	17.2
Mg	.22	.5	.34	.8	.06	.8	2.1
Ovendry weight		239		233		1,279	1,751

[1]An estimate of herbaceous vegetation was obtained in the summer of 1974 by clipping all herbaceous material on 25 subplots (2.7 ft^2) on control plots.

in height. On the burned plots, most of the aboveground parts of the hazel plants had been killed. The summer burns, however, proved more effective in reducing hazel sprouting than did the spring burns. The mean number of hazel stems by frequency of burns are shown in the following tabulation:

	No. of Stems (M/acre)
Unburned (control)	17 (4)[1]
Summer burned	
Annual	0 (0)
Biennial	4 (1)
Periodic	42 (8)
Spring burned	
Annual	38 (10)
Biennial	54 (17)
Periodic	59 (8)

Clearly the summer annual and biennial burns were effective in reducing hazel whereas the other burns were not. Although the 10 summer annual burns had eliminated the hazel, Buckman (1964) concluded that a single burn, if hot enough, would have accomplished the same result.

Visual observations on the annual summer burned plots in 1974 showed that very few hazel plants were growing indicating that hazel reinvades slowly after it has been eliminated.

In the fall of 1969, soil samples were collected from four soil pits on each plot at depths of 0 to 4, 4 to 20, and 20 to 39 inches. These were composited in the field, air-dried at room temperature, and sieved through a 2-mm screen. The fine fraction was used for all laboratory analysis and a correction was applied for the coarse materials.

The mineral soils were analyzed for particle size distribution by hydrometer and sieving (Day 1965), for nitrogen using the Kjeldahl method (Bremner 1965), and for hydrogen and aluminum using titration with NaOH after extraction with KCl (Yuan 1959). Calcium, magnesium, and potassium were extracted using 1*N* neutral ammonium acetate and determined by atomic absorption. Phosphorus was extracted using 0.01*N* HCl (Alban 1972) and determined colorimetrically. pH was determined in a 1:1 soil/water mixture. Cation exchange capacity (CEC) was taken as the sum of the bases plus H and Al.

[1]*Standard error of the mean shown in parentheses.*

Bulk density was assumed to be unaffected by burning (Lunt 1951, Metz *et al.* 1961). Therefore, only estimates for bulk density were made for each of the three depths based on measurements taken on sandy plots scattered throughout the Chippewa National Forest.

Forest floor samples were collected from 1-ft square areas on each plot by L, F, and H horizons. Forest floor ovendry weights were determined at 70°C.

Three representative hazel plants collected from each of the control plots (12 plants) constituted the shrub sample.

The shrub samples were ovendried at 70°C, after which the leaves were separated from the stems and the ratio of leaf to stem weight was determined. This ratio was used to estimate pounds per acre of the leaves and stems based on hazel volumes measured in 1969 and stem densities, which had been measured previously (Buckman 1966).

Samples of the forest floor and the understory plants were ground in a Wiley mill to pass a 20-mesh screen and redried at 70°C before nutrient analysis. The concentration of each nutrient in the forest floor and in the understory plants was determined as follows: N by Kjeldahl; and Ca, Mg, K, and P by ashing in a muffle furnace at 525°C for 2 hr followed by uptake in 3*N* HCl, and determination as for the mineral soils. An estimate of organic matter was made from the loss on ignition at 525°C. pH was determined using a 4:1 water/organic material ratio.

RESULTS AND DISCUSSION

Burning destroyed the L horizons on all plots and the F horizons on the annual and biennial burned plots. On the periodically burned plots, the F horizon was reduced but not eliminated. The color of the H horizons turned black because of charring and the downward movement of organic colloids. This horizon was compacted; and presumably it became less porous. Except for occassional darkening near the surface, changes in the mineral soil were not discernible.

The summer annual burns consumed all of the forest floor and exposed the mineral soil in patches covering less than 5 percent of the area of the burned plots. This agrees with Tarrant (1956), who reported that slash burning exposed mineral soil on less than 3 percent of the burned area in the Douglas fir region. However, studies involving more intense fires have been reported in which the mineral soil was left exposed on 25 to 50 percent of the study area (Van Wagner 1972).

Forest Floor

The organic matter in the forest floor was reduced by nearly one-half by the annual summer burns (table 4). This amounted to about 11,000 lb/acre, which corresponds with the amount of organic matter in the L and F horizons of the unburned plots (table 1). Thus, it appears the H horizon remains unburned even under the most intense burning, except in isolated patches where large amounts of fuel have accumulated.

Annual accumulation of litter to the forest floor can be roughly estimated as equal to the weight of the forest floor L horizon--about 3,810 lb-acre (table 1). This agrees with litterfall estimates for red pine reported by Chandler (1944), Lunt (1951), and Tappeiner and Alm (1975). However, it is about 50 percent greater than values reported by Alway and Zon (1930) and about 35 percent lower than those obtained under a 40-year-old red pine plantation on a sandy soil in northern Minnesota. It also agrees very closely with estimates published by Bray and Gorham (1964) for stands at latitudes comparable to Minnesota.

Shrub leaves contributed 233 lb to this estimate of 3,810 lb/acre; herbs, 239 lb (table 3). Thus, together they only accounted for approximately 12 percent of the total, which is comparable to the 15 percent reported by Scott (1955) for stands in Connecticut.

The contribution of the understory to the nutrient content found in the litter, however, is much greater than this 12 percent would indicate because of the high nutrient concentration in understory foliage. For example, the understory nutrient concentrations shown in table 3 are 1.5 to 5 times higher than those reported for overstory red pine trees by Hoyle and Mader (1964), Alban (1974), or Tappeiner and Alm (1975). Moreover, they are similarily higher than those found in the L horizon of the unburned plots, which were composed primarily of red pine foliage.

The same amounts of organic matter were left on the ground on all the summer burned plots after fire, regardless of frequency of burns. This can be derived by subtracting the amount of litter which has fallen onto the plots since the last fire from the total forest floor weight (table 4): for the summer biennial burns, subtract 1 years' litterfall (3,560 lb--table 1), and for the summer periodic burn, subtract 2 years' litterfall (7,120 lb).

The weight of the organic matter in the forest floor of the summer periodically burned plots averaged only 2,900 lb/acre less than the average for the unburned plots (table 4). This indicates that the organic matter in the forest floor returns rapidly to preburn levels.

Because all the spring burns were burned in 1969, the values of organic matter shown in table 4 are directly comparable. The slight decreases from annual to biennial to the periodic treatments probably can be attributed to more litter accumulating on the less frequently burned

Table 4.--*Effect of burning on the forest floor*

Treatment	pH	Organic matter	N	P	K	Ca	Mg	Months since last prescribed fire
		- - - - - - - - -	- -	*Lb/acre*	- - -	- - -	- - - -	
Control	4.91	23,400	395	29.0	57.3	340	42.5	--
Summer								
Annual	5.95*	12,400*	265*	21.8*	33.5*	289	33.0*	2
Biennial	5.72*	14,900*	287*	21.0*	40.2*	315	34.8*	14
Periodic	5.30*	20,500	343	22.9*	39.3*	323	35.6	26
Spring								
Annual	5.88*	18,600*	346	27.0	53.1	403	45.5	4
Biennial	6.00*	17,500*	348	28.2	70.2	438*	48.7	4
Periodic	5.86*	15,700*	298*	23.5*	55.0	322	36.5	4

*Indicates significant differences from the control at the 10 percent level.

plots, and that these caused hotter burns than those on the more frequently burned plots.

Nutrient and pH Changes

Lower amounts of N, P, K, Ca, and Mg were found in the forest floor on the annual summer burn plots than were found on the unburned plots (table 4). However, only the reduction in the amount of K was as pronounced as the reduction in organic matter. This indicates that some of the nutrients released during burning are retained, at least temporarily, within the remaining forest floor, which increases the concentration of bases in the forest floor. This along with the volatilization or organic acids during burning increased the pH from 4.91 to 5.95.

After the annual summer burns most of the released Ca, much of the released Mg, and little, if any, of the released K is retained within the forest floor (table 4). The strength with which cations are bound to exchange sites decreases in the order Ca>Mg>K (Black 1968, p. 237). Thus, the Ca released during burning is selectively absorbed into the exchange sites. The reduction in nitrogen in the forest floor is due to volatilization (Knight 1966) and possibly also to downward migration of organic material (DeBano *et al.* 1967).

After summer annual burning phosphorus also is reduced in the forest floor. P is released after burning as a negatively charged ion; therefore, it would not be expected to be held on the exchange sites in the forest floor because most of the sites are negatively charged. Most P in acid forest soils is held as iron and aluminum precipitates (Wild 1950). Therefore, P released after fire should be most strongly retained within the mineral soil where iron and aluminum are concentrated.

The biennial and periodic summer burns have affected the forest floor in much the same way as the annual burns except that the effect has been lessened somewhat by the litterfall on these plots since the last burn (table 4). The composition of the litterfall since the last burns on the biennially and periodically burn plots is probably similar to that in the L horizon of the unburned plots (table 1). It has increased the organic matter and nutrients and lowered the pH of the forest floor on the biennially and periodically burned plots.

The spring periodic treatment was burned in 1960 and 1969. Thus, by 1969 the L and F horizons and the shrub layer had built essentially back to their preburn level (Buckman 1964). Consequently, the 1969 fire would have consumed about 7,700 lb/acre of forest floor organic material (table 4) as well as about 1,279 lb/acre of shrub stems (control level table 3) consisting primarily of hazel, but with some willow, serviceberry, etc. Obviously with this amount of organic material consumed, there would be a large loss of nitrogen, and a sizeable deposition of nutrient-rich ash on the forest floor. This large deposition of nutrients has largely been leached from the forest floor as shown by the fact the P, K, Ca, and Mg actually are slightly lower on the spring periodic plots than on the control (table 4).

The annual and biennial spring burns substantially reduced the organic matter of the forest floor and increased its pH. The amounts of most nutrients are not significantly different from those on the unburned plots, but the trends indicate slight decreases of N and P, and increases of Ca and Mg.

Only on the annual and biennially spring burned plots was there evidence of nutrient accumulations in the forest floor. This can probably be attributed to the vigorous growth of the herbaceous vegetation on these plots. In 1969, for example, litter accumulations (L horizon) on the following were (lb/acre): spring annual burn plots, 4,530; spring biennial, 4,860; spring periodic, 3,160; and summer annual, 3,840. The greater litterfall on the spring annual and biennial burned plots is also considerably richer in nutrients than other plots due to the higher percentage of herbs (table 3). This indicates a greater degree of nutrient cycling occurred as a result of these burns.

Mineral Soil

The clay content was not significantly affected at any depth by the burns (table 5). Soil pH in the 0 to 4 inch layer was significantly increased after all except the summer periodic burns. Below 4 inches, there were no significant changes in pH.

Cation exchange capacity (CEC) was higher after burning in the 0 to 4 and

Table 5.--*Effect of burning on the mineral soil*

Depth (in.)	Treatment	Clay	CEC	pH	N	P	K	Ca	Mg
		Percent	*meq/100g*		- - - - - -	- *Lb/acre*	- - - - - -		
0 to 4	Control	5.0	3.15	5.32	654	186	75.1	438	54.3
	Summer (annual and biennial)[1]	4.4	3.17	5.53*	620	260*	69.6	471	58.7
	Summer (periodic)	4.3	3.36	5.44	663	226	67.8	496	65.1*
	Spring (all burns)[1]	5.4	3.65*	5.50*	683	252*	82.2	561*	67.2*
4 to 20	Control	4.9	1.71	5.65	784	1,260	135	827	140
	Summer (annual and biennial)[1]	4.2	2.15	5.71	852	1,210	174	1,260*	196
	Summer (periodic)	4.7	2.16	5.65	880	939	170	1,190	194
	Spring (all burns)[1]	5.0	2.57*	5.66	918	1,160	200*	1,520*	250*
20 to 39	Control	4.3	2.28	5.75	449	1,400	203	1,930	323
	Summer (annual and biennial)[1]	4.2	2.86*	5.84	492	1,540	207	2,460*	377*
	Summer (periodic)	5.0	2.17	5.82	508	1,230	181	1,900	320
	Spring (all burns)[1]	3.9	2.31	5.77	448	1,370	184	1,950	302

*Indicates significant differences from the control of the 10 percent level.
[1]Effects didn't differ significantly; therefore, these are combined.

particularly the 4 to 20 inch layers, even though only the effects of the spring burns were significantly different than those on the unburned plots. The summer annual and biennial burns increased cation exchange capacity in the 20 to 39 inch layer. The CEC of soils is largely a function of the kind and amount of clay and organic matter as well as of pH. The increases would require sizeable translocation of clay, which didn't occur. The pH changes do not seem adequate, particularly in the deeper layers, to explain the CEC changes either, although they might have played a minor role. It would seem that the downward translocation of organic material, as hinted at by the nitrogen increases, must be largely responsible for the increases CEC. Kononova (1961, p. 62) and Black (1968, p. 222) have reported that soil organic matter has a CEC measured in the hundreds of meq/100 g, and that the values increase as the pH rises. The very high CEC of the organic matter means that small amounts of organic matter when translocated downward in the profile of soils having low CEC can significantly increase the soil CEC.

An increase in CEC improves the capacity of the soil to hold cations. It is obvious in table 5 that Ca and Mg (the predominant cations on the exchange sites) have increased wherever the CEC has increased. It's noteworthy that all spring and the summer periodic burns produced the largest increases of Ca and Mg in the 4 to 20 inch layer but none in the 20 to 39 inch layer. The summer annual and biennial burns, however, produced large cation increases in both of these layers. This indicates that downward leaching of Ca and Mg was the most intensive after the summer annual and biennial burns. This would be expected because these burns would reduce more than other burns the amounts of understory vegetation available to intercept rainfall and the amount of forest floor to absorb and retain rainfall.

Soil nitrogen was not significantly altered by burning but the tendency was for slight increases in the 4 to 20 and 20 to 39 inch layers. This may represent the downward movement of organic material after burning that was observed by DeBano *et al.* (1967) and Smith (1970).

The phosphorus in the 0 to 4 inch layer increased considerably after burns, which reflects the limited mobility of phosphorus in acid soils. This concurs with Wild (1950) who reported that phosphorus is strongly retained by acid soils and with Cole and Gessel (1965) who showed that very little P moves below 36 inches in a gravelly soil even after clearcutting.

The effects of burning on the soil (tables 4 and 5) are the combined result of the most recent burn and the burning regime over the last 10 years. An indication of the importance of the last burn can be obtained from the data for the dormant season burns, all of which were burned in 1969. Both the forest floor and the mineral soils differed little among the three treatments even though the spring annual burns were burned 10 times whereas the spring periodic burns were burned only twice. Data from a similar study in South Carolina showed that prescribed burning for 10 years affected some soil properties but that continued burning for another 10 years resulted in little further soil changes Wells (1971).

CONCLUSIONS

Even though burning has reduced the amount of organic matter and nutrients in the forest floor, these losses are more than made up for by increases within the mineral soil. These soil changes and the unaffected tree growth suggest that prescribed fires resulting in volatilization of up to one half of the forest floor weight have had no affect on site productivity.

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Prescribed fires in mature red pine stands reduced shrub competition and the organic layer thickness. The fires reduced nutrients in the forest floor, increased them in the mineral soil, but had no effect on overstory growth.

OXFORD: 435.2:231.322:114.2. KEY WORDS: *Corylus cornuta*, forest floor, soil nutrients, understory, N, P, K, Ca, Mg.

Alban, David H.
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Prescribed fires in mature red pine stands reduced shrub competition and the organic layer thickness. The fires reduced nutrients in the forest floor, increased them in the mineral soil, but had no effect on overstory growth.

OXFORD: 435.2:231.322:114.2. KEY WORDS: *Corylus cornuta*, forest floor, soil nutrients, understory, N, P, K, Ca, Mg.

Put trash in the proper place.