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Long-Term Prescribed Burning Increases Nutrient Uptake and Growth of Loblolly Pine Seedlings

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ABSTRACT

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Loblolly pine (*Pinus taeda* L.) seedlings were grown from seed in a greenhouse on A1 horizon soil collected from field plots that have been burned each winter or maintained in an unburned condition for 33 years. Soils from burned and unburned plots were treated with phosphorus (P), P and calcium (Ca), or left untreated. After 32 weeks, height, biomass, and nitrogen (N) and P uptake were greater on soil from burned versus unburned plots, although application of P masked these effects. Addition of P increased plant biomass, seedling height, and uptake of N and P, but depressed levels of soil NH_4-N. These results suggest that long-term prescribed burning may have a positive effect on nutrient availability that will benefit seedlings of the next stand.

INTRODUCTION

Prescribed burning is a well-established tool used in the management of southern pine forests. The effect of prescribed burning on soil fertility, particularly total nitrogen (N) and extractable phosphorus (P), has been studied extensively. DeBell and Ralston (1970) reported that 62–85% of N contained in light fuels in the forest floor was volatilized upon burning. Wells (1971) and Kodama and Van Lear (1980) reported N losses ranging from 23 to 114 kg ha^{-1} from the forest floor. Others reported a loss of N from the forest floor but a simultaneous increase or no change in N in mineral topsoil (Klemmedson et al., 1962; McKee, 1982; McKee and Lewis, 1983). Little information is available on the effects of prescribed fire on N availability and uptake by seedlings.

More information is available on the effects of prescribed fire on extractable P. Wells (1971) reported that the weight of P in the forest floor was reduced by half on annual winter burn plots compared with controls, whereas extractable P in the mineral soil was simultaneously increased on the burn plots.

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Increases in extractable P on a wide variety of sites subjected to several types of prescribed burns were also reported by Moehring et al. (1966), Lewis (1974), McKee (1982) and McKee and Lewis (1983).

McNab and Ach (1977) reported that loblolly pine seedlings planted in the ashes of slash piles showed increased growth and survival compared with those planted in soil without overlying ashes. Little is known, however, on the effects of repeated prescribed burning throughout a rotation on nutrient uptake and growth of seedlings of the next stand. Our study was initiated to determine if 33 years of annual winter burning would alter the concentration of extractable N and P in the top 0–5 cm of soil in a mature stand of loblolly pine (*Pinus taeda* L.) and, if so, to determine the effects of burning on nutrient uptake and growth of seedlings.

METHODS

Loblolly pine seedlings were grown in a greenhouse in pots in a factorial arrangement of the randomized complete block design, with three blocks (replications) of two treatment factors. The factors were (1) annual winter burning for 33 years compared with no burning, and (2) three treatments of P fertilization. Phosphorus treatments were used because P is normally the most limiting nutrient to loblolly pine growth on lower coastal plain soils. A Ca plus P treatment was used to raise soil pH in association with increasing soil P. Seedling growth response on soil from burned plots could thus be compared with that on fertilized soils.

Soil was collected from field study plots on the Santee Experimental Forest, Berkeley County, SC. The plots are part of a 33-year ongoing study of annual winter prescribed burning or no burning (see McKee (1982) for a complete history of the prescribed burn study). The soil is classed as a sandy loam Wahee series (Aeric Ochraquults, clayey, mixed, thermic) and is somewhat poorly drained. The site has never been cultivated and supports a natural stand of loblolly pine.

The top 0–5 cm of mineral soil (A1 horizon) was collected from a 4-m^2 area on a burned and unburned plot from each of three blocks in the existing field study. Blocks in the field study corresponded to blocking in the greenhouse. The soil was shredded to pass a 1-cm screen and 7 kg (ovendry weight) of moist soil were placed into each of eighteen 25-cm pots lined with plastic. A 100-g sample was removed from each pot for chemical analysis before the application of fertilizer treatments. Treatments consisted of (1) no fertilizer, (2) P as monopotassium phosphate (KH_2PO_4) at 100 μg P g^{-1} soil, and (3) P as the above plus calcium (Ca) as calcium hydroxide ($Ca(OH)_2$) at 175 μg Ca g^{-1} soil, thoroughly mixed with the pot soil.

Loblolly pine seeds were germinated in sand and 10 seedlings were then transplanted to each pot. A single bench was used for pots within each block.

Positioning effects within blocks were minimized by rotating the pots weekly. Seedling heights were measured 10 weeks after potting and then once a month for the duration of the study. Thirty-two weeks after transplanting, seedlings were harvested intact by carefully washing soil from roots. Plant material was dried at 70°C for 24 h and then separated into roots, stems, and needles. All components were weighed and then ground to pass a 0.5-mm screen. Nitrogen concentration was determined by the salicylate-cyanurate method with autoanalysis after Kjeldahl digestion (Nelson and Sommers, 1973). A separate 1.0-g sample was dry ashed at 450°C for 2 h, taken up in 0.3 *N* HNO_3, and analyzed for P by the molybdovanadate procedure (Jackson, 1958) and for metals by atomic absorption. Nutrient content was expressed on a total plant dry-weight basis.

Two 2.5-cm soil cores were taken from each pot at harvest. Soil samples were air dried and crushed to pass a 2-mm sieve or fresh frozen for NH_4–N and NO_3–N analysis. Soil pH, total N, extractable NH_4–N, NO_3–N, and P, exchangeable K, Ca, Mg, and Na, organic matter, and texture were determined. Total N determination was as for plant material, whereas extractable NH_4–N and NO_3–N were determined by the method of Jackson (1958) and Hendricks and Selmer-Olsen (1970), respectively. Extractable P was determined by extraction with Bray 2 solution (Bray and Kurtz, 1945). Exchangeable bases in a 1.0 *N* NH_4OAC extract, soil pH in a 1 : 1 (*v*/*v*) soil-water slurry, and organic matter content were determined according to procedures of Jackson (1958). Soil texture was determined by the hydrometer method (Day, 1965). Measurement of atmospheric losses of N and P during the 33-year burning history of the field plots was beyond the scope of this study.

Both analysis of variance and *t*-tests were used to determine significant differences at the 0.05 level. Correlation coefficients were also determined to assess relationships between selected variables.

RESULTS

Soil properties

Before fertilization treatments, soil from annual winter burn plots had 1.75 $\mu g\ g^{-1}$ more extractable P, 0.57 meq 100 g^{-1} more exchangeable Ca, and pH values 0.3 units higher than soil from unburned plots (Table 1). Total N and extractable NH_4–N tended to be higher on soil from burned plots, but differences were not significant. Chemical properties measured at harvest indicated that soil from burned plots had 6.00 $\mu g\ g^{-1}$ more extractable P than soil from unburned plots.

Extractable NH_4–N was reduced by 45.0 and 56.4 $\mu g\ g^{-1}$ soil with the addition of P or P plus Ca, respectively (Table 1). Neither P nor P plus Ca amend-

TABLE 1

Chemical properties of soil from burned and unburned study plots before fertilizer treatment and at harvest and by fertilizer treatments at harvest

Soil property		Before treatment		At harvest[1]		P treatment[2]		
		Unburned	Winter burn	Unburned	Winter burn	No P	P	P+Ca
pH		4.3b	4.6a	4.2	4.3	4.1	4.4	4.3
Total N	$\mu g\ g^{-1}$	1444	1865	1564	1768	1700	1668	1630
Extract NH_4-N	$\mu g\ g^{-1}$	43.6	60.2	34.0	30.0	65.8a	20.8b	9.4b
Extract NO_3-N	$\mu g\ g^{-1}$	0.06	0.07	0.17	0.69	0.89	0.31	0.11
Extract P	$\mu g\ g^{-1}$	2.37b	4.12a	22.63b	28.63a	8.30b	32.75a	35.85a
Exch K	meq $(100\ g)^{-1}$	0.08	0.12	0.18	0.17	0.26	0.10	0.17
Exch Ca	meq $(100\ g)^{-1}$	1.02b	1.59a	1.64	2.07	2.29	1.34	1.94
Exch Mg	meq $(100\ g)^{-1}$	0.25	0.41	0.47	0.39	0.50	0.42	0.38
Exch Na	meq $(100\ g)^{-1}$	0.09	0.09	0.83	0.77	0.93	0.65	0.81

Values followed by a different letter within each sampling period or P treatment are significantly different at the 0.05 level.
[1]Phosphorus treatment values combined (No P, P, and P+Ca).
[2]Burn treatment values combined (unburned and winter burn).

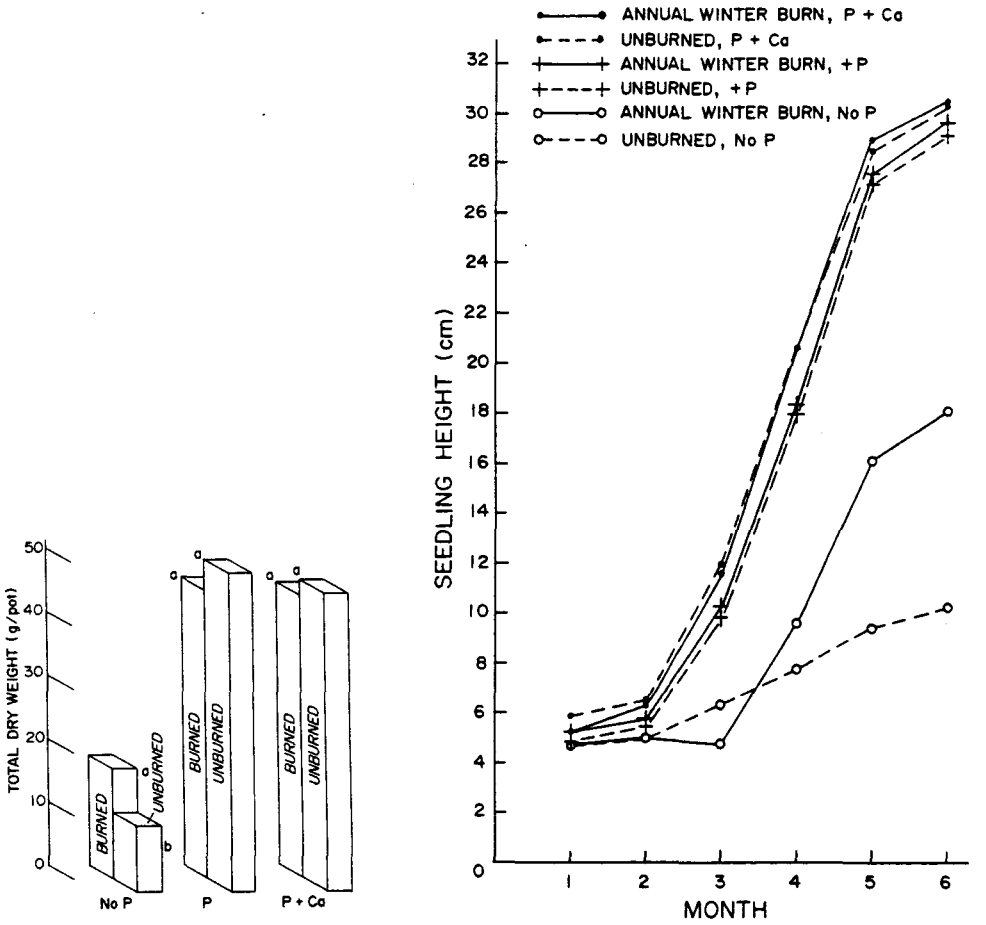

Fig. 1. Biomass of loblolly pine seedlings grown for 32 weeks on soils with different fertilization and burning histories. Paired columns with different letters are significantly different at the 0.05 level.

Fig. 2. Loblolly pine seedling height growth on soils with different fertilization and burning histories.

ments caused significant changes in other soil properties except for an increase in extractable soil P.

Seedling growth

Pine seedlings grown in soil from burned plots had more than twice the biomass (Fig. 1) and heights were almost twice those of control seedlings (Fig. 2) when no fertilizer was added. Addition of P quadrupled seedling biomass and doubled seedling heights compared with unfertilized seedlings. Burning

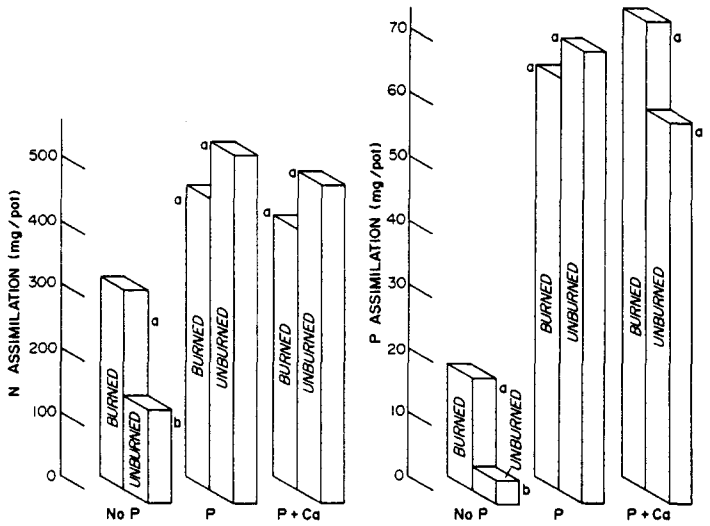

Fig. 3. Nitrogen (N) and phosphorus (P) assimilation by loblolly pine seedlings grown for 32 weeks on soils with different fertilization and burning histories. Paired columns with different letters are significantly different at the 0.05 level.

did not significantly affect seedling height or biomass when all P treatments were combined.

Nutrient uptake

Unfertilized seedlings grown in soil from burned plots accumulated 162.9 mg per pot more N and 13.8 mg per pot more P than seedlings grown in control soil (Fig. 3). Both P amendments significantly increased the total seedling uptake of all observed nutrients compared with no P controls. Total nutrient content of seedlings was not significantly affected by burn treatment when all P treatments were combined.

DISCUSSION

Results of this experiment indicate that 33 years of annual winter prescribed burning in a loblolly pine stand improved soil fertility. An increase in extractable P, which is usually the most limiting nutrient in coastal plain soils, was the most obvious effect of burning on soil properties. There were no adverse effects of burning on total N or extractable NH_4–N and NO_3–N concentrations in the soil.

Phosphorus fertilization had a strong influence on NH_4–N transformations and/or uptake as shown by a highly significant negative correlation coefficient (-0.82) between extractable P and NH_4–N at harvest. Significantly less

NH_4–N was extracted from the soil at harvest when P was applied. The increase in root biomass due to fertilization with P may have allowed the seedlings to exploit a larger volume of soil within the pot and remove larger quantities of NH_4–N than roots of unfertilized seedlings. Even though long-term prescribed burning increased extractable P, the increases were not sufficient to duplicate effects of P fertilization on extractable NH_4–N. Concentrations of extractable P in soils from burned plots were only one-sixth to one-third those from fertilized soils. This relationship, as well as N volatilization during a fire may account for the lack of measureable increases in extractable NH_4–N after burning, as reported above.

Growth of loblolly pine seedlings in the absence of P additions was enhanced by long-term, annual winter burning. Seedling heights, biomass, and nutrient accumulations were greater on soil from burned plots. This suggests that N and P were more available to the seedlings. Phosphorus amendments greatly increased pine seedling height, biomass, and total uptake of all nutrients, regardless of burn treatment. Seedling response to burning was not detectable with the application of P. In summary, these results suggest that the systematic use of annual prescribed fires in the management of loblolly pine stands can be beneficial to seedling establishment in terms of increased nutrient availability and seedling growth, yet burning does not provide the same level of response as P fertilization.

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