Reprinted from

Forest Ecology and Management

Forest Ecology and Management 70 (1994) 311–318

Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands

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Accepted 22 March 1994

Forest Ecology and Management

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Publication information: *Forest Ecology and Management* (ISSN 0378-1127). For 1994 volumes 62–70 are scheduled for publication. Subscription prices are available upon request from the Publisher. Subscriptions are accepted on a prepaid basis only and are entered on a calendar year basis. Issues are sent by surface mail except to the following countries where Air delivery via SAL mail is ensured: Argentina, Australia, Brazil, Canada, Hong Kong, India, Israel, Japan, Malaysia, Mexico, New Zealand, Pakistan, PR China, Singapore, South Africa, South Korea, Taiwan, Thailand, USA. For all other countries airmail rates are available on request. Claims for missing issues should be made within six months of our publication (mailing) date. Please address all your requests regarding orders and subscription queries to: **Elsevier Science B.V., Journal Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands, tel. (+31-20) 5803642, fax (+31-20) 5803598.**
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USA POSTMASTERS: Send address changes to *Forest Ecology and Management* Publications Expediting, Inc., 200 Meacham

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Forest Ecology and Management 70 (1994) 311–318

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Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands

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Accepted 22 March 1994

Abstract

Over a period of 16 years, unburned longleaf pine (*Pinus palustris* Mill.) pole stands grew an average of 27% more volume than similar stands regularly burned. Treatments included biennial burns in winter, spring, and summer plus an unburned check, each of which was combined with three supplemental treatments, namely, initial herbicide injection of all hardwoods, repeated handclearing of all woody stems, and no treatment. All unburned and winter-burned plots were paired to study this growth reduction relative to treatments. The status of nitrogen, phosphorus, available moisture holding capacity, bulk density, and macropore space was determined in both surface and subsurface soils. Foliage from pines on sampled plots was analyzed for N, P, K, Ca, Mg, Mn, Cu, Fe, and Zn. Burning did not significantly affect either soil N and P or foliar nutrients. However, burning reduced available moisture holding capacity and macropore space and increased the bulk density of surface soils, and also reduced the moisture-holding capacity of subsurface soils. The results from this and other studies suggest that growth losses are due, at least in part, to increased moisture stress associated with changes in soil physical properties.

Keywords: Prescribed fire; *Pinus palustris* Mill.; Stand growth; Hardwood control; Herbicide injection; Understory clearing

1. Introduction

Over a period of 10 years, biennial winter, spring, and summer prescribed fires significantly reduced the height and diameter growth of sapling-pole size longleaf pines (Boyer, 1987). Stand volume growth from Age 14 to 24 averaged 27% higher in unburned than in burned stands. Growth was unaffected by season of burn. The volume growth differential between burned and unburned stands has continued at the same rate to stand Age 30 (Boyer, 1994). Reasons for this growth reduction associated with burning are not apparent. Fire intensities were low, partly as a result of the frequency of burning that kept fuel accumulations low. Crown scorch did not seem to be a factor, averaging less than 5% for four successive series of winter burns. Crown scorch alone is not expected to affect pine growth before it exceeds one-third of the live crown (Waldrop and Van Lear, 1984; Lilieholm and Hu, 1987).

Results from past studies have been inconclusive. Surface fires of low to moderate intensity have reduced growth of small longleaf pines (Garren, 1943; Wahlenberg, 1946; Bruce, 1947), presumably owing to defoliation, but were not

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SSDI 0378-1127(94)03395-D

expected seriously to affect development of this fire-tolerant species once beyond the sapling stage. In mature or maturing longleaf stands, no growth reductions were observed with periodic burning (Garren, 1943; Sackett, 1975), whereas annual burning for long periods (30 years) reduced both height and diameter growth (Bruce, 1947). Stone (1942) reported that fire resulted in diameter growth reductions over a wide range of tree sizes, indicating that frequently burned longleaf pine stands will be unsuitable for preparation of yield tables. Diameter growth reductions have also been noted in 20- to 35-year-old longleaf stands during the year following a winter burn (Zahner, 1989). This growth loss was greatest in dry years, and less or non-existent in wet years, suggesting a connection with moisture availability.

Early studies of surface fire effects on nutritional and physical properties of soils in the southeastern coastal plain suggested that, on balance, fires had slightly detrimental effects on physical properties and slightly beneficial effects on nutrition. Southern soils protected from fire were more penetrable and porous than frequently burned soils (Wahlenberg, 1935; Heyward, 1936), but recovery appeared rapid after burning was stopped (Heyward, 1937). Early reports also indicated that surface soils in burned stands tended to have higher levels of N, Ca, and other minerals, more organic matter, and higher pH (Wahlenberg, 1946).

More recent studies tend to support these earlier findings and expand the understanding of fire effects on N pools and losses. Periodic burns in coastal plain pine stands increased macronutrients (Metz et al., 1961; Hough, 1981; McKee, 1982; Linnartz, 1984) while not adversely affecting N and organic matter in surface soils (Metz et al., 1961; McKee, 1982). Increased availability of N in surface soils following burning has been reported (Schoch and Binkley, 1986). However, losses in forest floor N and organic matter were shown by McKee (1982) with increased frequency of burning. Furthermore, N is lost from burned forest sites through volatilization, from 30% to 60% of fuel content (DeBell and Ralston, 1970; Wells, 1971; Vose and Swank, 1993). Replacement of this N loss can occur through fire-stimulated symbiotic and non-symbiotic N-fixation (Wells, 1971; Jorgensen and Wells, 1971). Thus, non-volatile nutrients are mineralized through combustion and transported into the soil, and volatile N is lost, although N replacement can be initiated with a fire event (Waldrop et al., 1987).

The study reported here was superimposed on a long-term burning study (Boyer, 1987) to determine whether 10 years of repeated prescribed fires, in combination with additional woody plant control treatments, had affected soil N and P, available moisture holding capacity, bulk density, and macropore space or the nutrient status of pine foliage. If causes for the reduced pine volume growth associated with burning can be identified, it may become possible to manage prescribed fires so as to obtain the needed benefits with minimum impact on growth.

2. Methods and procedures

2.1. Study area

The original study was initiated in 1973 to determine long-term effects of several hardwood control treatments on composition and structure of the understory and also growth of overstory pine. The study was established on the Escambia Experimental Forest (maintained by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the T.R. Miller Mill Co.), in southwest Alabama, on a typical coastal plain longleaf pine site. Soils were primarily fine sands of the Troup series (loamy, siliceous, thermic Grossarenic Paleudults), with some Dothan (fine-loamy, siliceous, thermic Plinthic Paleudults), Wagram (loamy, siliceous, thermic Arenic Paleudults), and Fuquay (loamy, siliceous, thermic Arenic Plinthic Kandiudults) series represented, all with slopes of less than 5%. Study areas contained even-aged longleaf pine stands originating primarily from the 1958 seed crop and released from residual seed trees in winter 1961. All study areas had been periodi-

cally burned in the past, although the last fire before the study began was in January 1962.

2.2. Study design

The parent study consists of three separate blocks, each with 12 square 0.16 ha plots. All plots were thinned to a density of 1236 trees ha^{-1} at study establishment. After thinning, residual pines averaged 6.7 m in height, 8.1 cm diameter at breast height (dbh) and 6.9 m^2 basal area ha^{-1}. Indicated Age 50 site index (Farrar, 1981) for the three study blocks, derived from dominant/codominant tree heights on unburned plots at Age 30, averaged 23–25 m. Twelve treatment combinations were randomly assigned among plots in each block using a factorial design. Each of four burning treatments (biennial prescribed fires in winter, spring, summer, and an unburned check) was combined with three supplemental treatments: (1) initial hardwood control by stem injection with 2,4-D; (2) repeated handclearing of all woody vegetation 1.4 m or more in height, as needed; (3) an untreated check. Supplemental treatments were initiated in spring 1973. All burning treatments began with a conditioning winter burn in January 1974, with assigned seasonal burns beginning during the succeeding year. Burning techniques were adapted to site and weather conditions. Sixty per cent of plot burning was done with strip headfires, 24% with backfires, and the rest with flank fires.

This study began in 1984. The three unburned plots were paired with the three winter-burned plots in each block. As pine growth responses among seasons of burn were similar, causes are expected to be the same. The winter burning treatment was selected because most prescribed burning in longleaf pine forests has been done during the winter.

2.3. Field sampling

2.3.1. Soils

In each of the six plots per block, soil samples were collected from two depths along a diagonal transect across 0.04 ha net plots. Twelve samples each were collected from the 0–15 cm and 15–30 cm depths and composited by plot and depth. At every other sampling point (six per plot) two undisturbed soil core samples (45 cm^3) were taken from the 0–5 cm and 15–20 cm depths. Samples were collected in July 1984, after a burn in the preceding January, and held in cold storage (4°C) until analyzed.

2.3.2. Foliage

Foliage was collected from five randomly selected sample pines on each net plot. Six complete fascicles from the first growth flush of 1984 were collected from each sample tree in late June 1984. Samples were placed in plastic bags as collected and then frozen until prepared for laboratory analysis. Foliage from each sample tree was collected again in spring 1986. Twenty complete fascicles from the first flush of 1985 growth were taken from shoot terminals or laterals in the upper third of the crown. All 100 needle fascicles per plot were combined, frozen on return from the field, and kept frozen pending laboratory analysis.

2.4. Analysis procedures

2.4.1. Soils

Composite soil samples were air dried and crushed to pass through a sieve of 2 mm mesh. Soil P was extracted from quadruplicate 5 g soil samples using 20 ml of a weak double acid solution (Mehlich, 1953) and determined using the method described by Murphy and Riley (1962) to yield an estimate of available P. Total soil N was determined from quadruplicate samples using Kjeldahl digestion and an ammonia-specific ion electrode (Bremner and Tabatabai, 1972; Eastin, 1976). Available moisture holding capacity, as per cent by volume, was calculated from undisturbed soil cores using pressure extraction. The difference in moisture content at 0.03 and 1.5 MPa tension provided an estimate of the capacity of sampled soils to hold moisture within the range available for plant uptake. Soil bulk density was determined from cores after oven-drying to a constant weight at 105°C. Per cent macropore space was obtained from core

Table 1
Available moisture holding capacity ($m^3 m^{-3}$) of the soil as affected by hardwood control treatments

Burn	Supplemental treatment			Average
	Inject	Clear	None	
0–5 cm depth				
None	15.3	12.2	15.0	14.2a
Winter	9.9	11.1	10.0	10.3b
Average	12.6a	11.6a	12.5a	12.2
15–20 cm depth				
None	13.1	12.9	13.9	13.3a
Winter	11.1	10.9	10.8	10.9b
Average	12.1a	11.9a	12.3a	12.1

Column or row means followed by the same letter do not differ at the 0.05 level of significance.

Table 2
Bulk density and macropore space of surface soil samples

	Bulk density ($g cm^{-3}$)	Macropore space (%)
No burn	1.22	47.1
Winter burn	1.26	44.5

samples as the water volume difference between saturation and 0.03 MPa tension.

2.4.2. Foliage

Foliage samples were oven-dried (70°C), ground to pass a screen of 0.0425 mm mesh, and retained in cold storage for nutrient analyses. The 1984 foliage collection was analyzed for N and P. The 1986 foliage collection was analyzed for N, K, Mg, Mn, Ca, Cu, Fe, and Zn. Foliar N was determined from duplicate 0.1 g samples of ground foliage following the same procedure as described above for soil samples. Foliar mineral elements were determined from 0.5 g duplicate samples after dry-ashing at 450°C for at least 6 h. When cooled, 20 ml of 0.4 N HCl with 0.2% lanthanum was added. After mixing and filtering, P was determined by the vanado-molybdate method (Jackson, 1958). The concentration of K, Ca, Mg, Mn, Cu, Fe, and Zn in clear, undiluted extract was determined by atomic absorption spectrophotometry.

2.5. Statistical analyses

Analysis of variance procedures were used to test for significant treatment differences (a= 0.05). Per cent values were transformed to arcsin square-root. If treatment effects were significant at the 0.05 level, treatments means were separated using Duncan's multiple range test. Paired t-tests were used to compare within-cell values for soil N and P between burned and unburned plots due to a significant treatment interaction.

3. Results

3.1. Soils

The available moisture holding capacity of soils was significantly lower, by 27% surface and 18% subsurface, with the winter burn than with the no-burn treatment (Table 1). Supplemental treatments had no significant effect.

Winter burning significantly increased bulk density and reduced per cent macropore space of surface but not subsurface soils. Values for surface soil samples are given in Table 2. Supplemental treatments had no effect on these two variables.

Burning did not significantly affect total N or available P in either surface or subsurface soils, but supplemental treatments did. Periodic fell-

Table 3
Soil nitrogen per cent as affected by hardwood control treatments

Burn	Supplemental treatment			Average
	Inject	Clear	None	
0–15 cm depth				
None	0.044a[1]	0.045a	0.041a	0.044a
Winter	0.037a	0.057a	0.040a	0.044a
Average	0.040b[2]	0.051a	0.041b	0.044
15–30 cm depth				
None	0.032a	0.025a	0.020a	0.026a
Winter	0.018b	0.034a	0.026a	0.026a
Average	0.025ab	0.029a	0.023b	0.026

[1] Column or [2] row means followed by the same letter do not differ at the 0.05 level of significance.

Table 4
Extractable soil phosphorus (mg kg^{-1}) as affected by hardwood control treatments

Burn	Supplemental treatment			Average
	Inject	Clear	None	
0–15 cm depth				
None	0.38a[1]	0.52a	0.70a	0.54a
Winter	0.75a	0.80a	0.52a	0.69a
Average	0.57a[2]	0.66a	0.61a	0.61
15–30 cm depth				
None	0.33a	0.33a	0.47a	0.38a
Winter	0.20a	0.53a	0.33a	0.36a
Average	0.27b	0.43a	0.40ab	0.37

[1] Column or [2] row means followed by the same letter do not differ at the 0.05 level of significance.

Table 5
Nitrogen and phosphorus contents in pine needles

	Nitrogen	Phosphorus
No burn	0.88	0.03
Winter burn	0.84	0.03

ing of woody plants resulted in significantly more N in surface soils, and also raised N levels in subsurface soils compared with plots where woody understory plants were not cut (Table 3). The highest N levels were found on plots where woody plants were repeatedly cut and burned.

Nitrogen consistently decreased with depth, and the lowest level of N occurred on plots that

Table 6
Nutrient values for burned and unburned plots

	Winter burn (mg kg^{-1})	No burn (mg kg^{-1})
Nitrogen	8900	9000
Potassium	3490	3200
Calcium	2250	2080
Magnesium	950	990
Manganese	170	201
Iron	28	30
Zinc	26	24
Copper	2.8	3.1

were both injected and burned. This was significantly lower than on injected–unburned plots. Contrary to some earlier reports (Metz et al., 1961; McKee, 1982), frequent burning alone did not consistently result in a higher level of N in the soil.

Available P was not significantly affected by supplemental treatments in surface soils. However, available P in subsurface soils was significantly higher on repeatedly cleared plots than on those with the injection treatment (Table 4). For all supplemental treatments combined, available P, like N, was not consistently higher with burning.

3.2. Foliage

Neither burning nor supplemental treatments significantly affected N and P content of pine foliage collected in 1984. Percentages of these elements in pine needles are given in Table 5.

Nutrient analyses of foliage collected in 1986 also did not reveal any significant differences owing to burning or supplemental treatments. The average values for burned and unburned plots are given in Table 6.

4. Discussion and conclusions

Biennial winter burning did not significantly affect either the N or P content of soils or of longleaf pine foliage when compared with similar stands unburned for 22–24 years. Burning also did not affect foliar content of K, Ca, Mg, Mn, Cu, Fe, and Zn. The longleaf pine growth reductions associated with biennial burns in this study do not seem to be due to changes in nutrient availability and utilization. This supports conclusions from a number of studies reporting no deleterious effects of periodic fire on nutrient availability when low-intensity burning was used, except the volatile loss of N from the site (DeBell and Ralston, 1970; Wells, 1971). Wells's (1971) findings in a pot study suggest less N availability on burned soils.

Biennial winter burning was associated with a significantly reduced moisture retention capacity, increased bulk density, and decreased macropore space in surface soils, and also with a reduced moisture retention capacity in subsurface soils. Wahlenberg et al. (1939) reported that annual burning on a coastal plain soil increased soil bulk density from 1.3 to 1.4 g cm^{-3} and reduced porosity from 42 to 40% compared with similar unburned soils. These changes are similar to those observed in this study. Ralston and Hatchell (1971) noted that, with repeated moderate burning over long periods, decreases in macropore space, infiltration, and aeration can be expected. This results from exposure of mineral soil to rainfall, with consequent dispersal of aggregates that can clog soil pores (Bower, 1966; Moehring et al., 1966). They also noted that reductions in percolation rates are sometimes observed after fires on sandy soils, as a result of resistance to wetting that impedes downward infiltration of water. However, when prescribed fires do not completely remove surface organic matter, changes in infiltration and pore space may be too small to detect.

The negative impact of biennial burning on pine growth could be associated with the regular removal of surface organic matter. The physical removal of litter from a longleaf pine plantation resulted in a diameter growth reduction during the year immediately following removal (McLeod et al., 1979). This rapid response to litter removal suggested a change in water entry and infiltration, as macronutrient concentrations in pine foliage were not affected. Further, measurements of xylem pressure potential indicated increased moisture stress in trees on plots with litter removed compared with trees where litter remained intact (Ginter et al., 1979). This difference in moisture stress between treated and control plots continued throughout the first season regardless of rainfall or drought. Heyward (1939), noting the higher moisture content of surface soil horizons in unburned compared with burned longleaf pine stands, suggested that the mulching effects of surface organic litter on unburned soils might be partly responsible.

It is difficult to believe that the relatively small changes in soil moisture holding capacity observed in this study could be responsible for an

annual pine volume growth reduction in all winter-burned plots averaging 2.17 m^3 ha^{-1} (20%) for the 16 years from Age 14 to 30. The average diameter growth reduction over this period was 9%. Zahner (1989) reported that, with other factors held constant, longleaf pine ring width during the year following a winter burn was reduced an average of 13% in stands from 20 to 28 years old. A 12% diameter growth difference in mature longleaf stands (50–60 years old) was observed between unburned stands and similar stands with biennial prescribed fires (Boyer, 1987). Highly variable reductions in longleaf pine radial growth following fire were reported by Stone (1942). Radial growth reductions averaged 23% during the year after a burn for pines under 15.2 cm dbh, and 19% for larger trees. Stone assumed that growth reductions were due to defoliation by fire.

The major impact of fire (Stone, 1942; Zahner, 1989) or surface litter removal (McLeod et al., 1979) on longleaf pine growth occurred during the first year after treatment, and was much diminished or absent in the second year. The fact that growth responses to both litter removal and fire were so similar suggests that causal factors are more probably related to changes in soil moisture conditions than to defoliation from crown scorch. That the growth reduction is confined largely to the first year after fire or litter removal is not entirely consistent with a permanent change in soil physical properties resulting from the absence of fire; unless, of course, conditions improve so rapidly that by the second or third year after a fire, soil moisture availability and related tree growth conditions are essentially equivalent to those within a stand unburned for 10 years or more.

The results to date strongly suggest that longleaf pine growth reductions associated with periodic prescribed fires may be due to changes in soil–tree moisture relations. Further investigations on the impacts of prescribed burning on longleaf pine growth should concentrate on changes in the physical properties of the soil, including soil organic layers, and possible changes in surface fine-roots and mycorrhizae, that may affect soil moisture availability and uptake by the tree.

References

Bower, D.R., 1966. Surface soil recovers quickly after burn. US For. Serv. Res. Note, S0-46, 2 pp.

Boyer, W.D., 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? South. J. Appl. For., 11: 154–157.

Boyer, W.D., 1994. Eighteen years of seasonal burning in longleaf pine: effects on overstory growth. In: Proceedings 12th International Conference on Fire and Forest Meteorology, 26–28 October 1993, Jekyll Island, GA. Society of American Foresters, Bethesda, MD, pp. 602–610.

Bremner, J.M. and Tabatabai, M.A., 1972. Use of ammonia electrode for the determination of ammonia in Kjeldahl analysis of soils. Commun. Soil Sci. Plant Anal., 3: 159–165.

Bruce, D., 1947. Thirty-two years of annual burning in longleaf pine. J. For., 45: 809–814.

DeBell, D.S. and Ralston, C.W., 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Am. Proc., 34: 936–938.

Eastin, E.F., 1976. Use of ammonia electrode for total nitrogen determination in plants. Commun. Soil Sci. Plant Anal., 7: 477–481.

Farrar, Jr., R.M., 1981. A site-index function for naturally regenerated longleaf pine in the east Gulf area. South. J. Appl. For., 5: 150–153.

Garren, K.H., 1943. Effects of fire on vegetation of the southeastern United States. Bot. Rev., 9: 617–654.

Ginter, D.L., McLeod, K.W. and Sherrod, Jr., C., 1979. Water stress in longleaf pine induced by litter removal. For. Ecol. Manage., 2: 13–20.

Heyward, F., 1936. Soil changes associated with forest fires in the longleaf pine region of the South. Am. Soil Survey Assoc. Bull., 17: 41–42.

Heyward, F., 1937. The effect of frequent fires on profile development of longleaf pine forest soils. J. For., 35: 23–27.

Heyward, F., 1939. Some moisture relationships of soils from burned and unburned longleaf pine forest soils. Soil Sci., 47: 313–327.

Hough, W.A., 1981. Impact of prescribed fire on understory and forest floor nutrients. US For. Serv. Res. Note, SE-303, 4 pp.

Jackson, M.L., 1958. Soil Chemical Analysis. Prentice-Hall, Englewood Cliffs, NJ, 498 pp.

Jorgensen, J.R. and Wells, C.G., 1971. Apparent nitrogen fixation in soil influenced by prescribed burning. Soil Sci. Soc. Am. Proc., 35: 806–810.

Lilicholm, R.J. and Hu, S.C., 1987. Effect of crown scorch on mortality and diameter growth of 19-year-old loblolly pine. South. J. Appl. For., 11: 209–211.

Linnartz, N.E., 1984. Effects of prescribed burning on some

chemical properties of forest soils. LSU Forestry Notes No. 141, Louisiana Agric. Exp. Stn., Baton Rouge, LA, 2 pp.

McKee, Jr., W.H., 1982. Changes in soil fertility following prescribed burning on coastal plain pine sites. US For. Serv. Res. Pap., SE-234, 23 pp.

McLeod, K.W., Sherrod, Jr., C. and Porch, T.E., 1979. Response of longleaf pine plantations to litter removal. For. Ecol. Manage., 2: 1–12.

Mehlich, A., 1953. Determinations of P, Ca, Mg, K, Na, and NH_4 by North Carolina soil testing laboratories. North Carolina State University, Raleigh (mimeo).

Metz, L.J., Lotti, T. and Klawitter, R.A., 1961. Some effects of prescribed burning on coastal plain forest soil. US For. Serv. Sta. Pap., 133, 10 pp.

Moehring, D.M., Grano, C.X. and Bassett, J.R., 1966. Properties of forested loess soils after repeated prescribed burns. US For. Serv. Res. Note, S0-40, 4 pp.

Murphy, J. and Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, 27: 31–36.

Ralston, C.W. and Hatchell, G.E., 1971. Effects of prescribed burning on physical properties of soil. In: Proceedings, Prescribed Burning Symposium, 14–16 April 1971, Charleston SC. US For. Serv., Southeastern For. Exp. Stn., Asheville, NC, pp. 68–85.

Sackett, S.S., 1975. Scheduling prescribed burns for hazard reduction in the southeast. J. For., 73: 143–147.

Schoch, P. and Binkley, D., 1986. Prescribed burning increased nitrogen availability in a mature loblolly pine stand. For. Ecol. Manage., 14: 13–22.

Stone, E.L., 1942. Effect of fire on radial growth of longleaf pine. US For. Serv. South. For. Exp. Stn. Note, 43, 3 pp.

Vose, J.M. and Swank, W.T., 1993. Site preparation burning to improve southern Appalachian pine–hardwood stands: aboveground biomass, forest floor mass, and nitrogen and carbon pools. Can. J. For. Res. 23: 2255–2262.

Wahlenberg, W.G., 1935. Effect of fire and grazing on soil properties and the natural reproduction of longleaf pine. J. For., 33: 331–338.

Wahlenberg, W.G., 1946. Longleaf pine: its use, ecology, regeneration, protection, growth, and management. Charles Lathrop Pack Forestry Foundation in cooperation with USDA For. Serv., Washington, DC, 429 pp.

Wahlenberg, W.G., Greene, S.W. and Reed, H.R., 1939. Effects of fire and cattle grazing on longleaf pine lands as studied at McNeill, Mississippi. US Dep. Agric. Tech. Bull., 683, 52 pp.

Waldrop, T.A. and VanLear, D.H., 1984. Effect of crown scorch on survival and growth of young loblolly pine. South. J. Appl. For., 8: 35–40.

Waldrop, T.A., VanLear, D.H., Lloyd, F.T. and Harms, W.R., 1987. Long-term studies of prescribed burning in loblolly pine forests of the southeastern coastal plain. US For. Serv. Gen. Tech. Rep., SE-45, 23 pp.

Wells, C.G., 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. In: Proceedings, Prescribed Burning Symposium, 14–16 April 1971, Charleston, SC. US For. Serv., Southeastern For. Exp. Stn., Asheville, NC, pp. 86–99.

Zahner, R., 1989. Tree-ring series related to stand and environmental factors in south Alabama longleaf pine stands. US For. Serv. Gen. Tech. Rep., S0-74: 193–197.

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0378-1127/94/$07.00

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Printed in The Netherlands

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1994 SUBSCRIPTION DATA

Volumes 28-30 (in 9 issues)
Subscription price:
Dfl. 1080.00 (US $ 584.00)
incl. Postage
ISSN 0169-2046

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