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Effects of Low Intensity Prescribed Fire on the Growth and Nutrition of a Slash Pine Plantation

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Abstract

The effects of prescribed fire on the growth and nutrition of slash pine (*Pinus elliottii*, Engelm var. *elliottii*) have been monitored for 9 years, following repeated prescribed burning in the large exotic plantation areas of the coastal lowlands of south-east Queensland. Two treatments, no burning and low intensity burning every 3 years, have been applied since the stands were 13 years old.

No overall differences in diameter or height growth were detected between treatments. Increases in pH, nitrogen and exchangeable cations were found in samples of the soil surface layer (0–2·5 cm) immediately after burning, but these appear to be of short duration as there were no significant differences between treatments 3 years later. Exchangeable cations and organic carbon in the soil surface layer were found to have declined as a result of repeated burning but no long-term differences were detected in other soil parameters.

[O.D.C. 436 : 181.32 : 181.65 : 174.7 *Pinus elliottii*]

Introduction

Forest fire behaviour is markedly influenced by the arrangement and quantity of fine fuel, and prescribed burning is the most effective and efficient technique to reduce both the quantity and suspension of this fuel. While the technique may not appreciably lessen the risk of non-prescribed fires occurring, any outbreaks are much easier to suppress. Prescribed burning has been used in the natural stands of slash pine since early this century but was not applied to the slash pine plantation areas of Queensland until the early 1970s. The initial system of regularly burnt buffer strips has since been expanded and virtually all of the plantation area will be burnt at least once in the rotation.

Established in 1972, the experiment described here forms part of a series set up to monitor the effects of prescribed burning on slash pine at four sites in Queensland. Byrne (1980), in an overview of these experiments, reported that prescribed burning had not affected diameter and height growth, except where crown scorch had occurred. The aim of this paper is to further examine the effect of low intensity burning every 3 years on one of these sites. Diameter and height growth from 1972 to 1981, based on the original pairing of treatment plots, and the foliar and soil nutrient levels over this period are discussed.

Site Description, Silvicultural History and Treatments

The experiment is located in State Forest 915 Tuan, an exotic conifer plantation of approximately 35 000 ha south of Maryborough. It is in Compartment 6A Tahiti Logging Area at lat. 25° 49′ S. and long. 152° 49′ E. Tuan has a pronounced summer rainfall pattern from January to March with each of these months averaging over

200 mm. The yearly average since 1948 is 1350 mm. The coldest mean monthly temperature is 13°C in July and the hottest is 24°C in February.

The site is level or slightly undulating, with the aspect ranging from north-east to northerly. Soils in the area are lateritic podzolics (Stace *et al.* 1968): the upper layers are loamy sand with the lower layers being sandy loam to sandy clay loam. The original vegetation in the area was a tall open-forest (Specht 1970). Major overstorey species present prior to clearing were *Eucalyptus drepanophylla*, *E. signata* and *E. intermedia* and to a lesser extent *Angophora costata* and *Tristania sauveolens*. Species common in the understorey were *Casuarina torulosa* and *C. littoralis*, *Banksia integrifolia*, *Alphitonia excelsa*, *Acacia flavescens*, *A. aulacocarpa*, *A. complanata*, *Hakea plurinervia* and *Lomatia salicifolia*.

The 32·9 ha compartment was cleared, windrowed and burnt in 1958 and planted in winter 1959 with stock raised from an unimproved seed batch. The original stocking of 1680 stems ha^{-1} was reduced to 1000 stems ha^{-1} by pre-commercial thinning at age 11 years. Ground rock phosphate at 320 kg ha^{-1} was applied 3 months after planting to supply 50 kg ha^{-1} phosphorus. Weed control by brushing and herbicide spraying was carried out as necessary for the first 11 years. Pruning of the compartment was as follows:

Dec. 1967 (age 8·5 yr):	ground prune 400 stems ha^{-1} to 2·4 m;
Oct. 1968 (age 9·3 yr):	second prune 275 stems ha^{-1} to 4·4 m;
Dec. 1970 (age 11·5 yr):	final prune to 6·4 m.

The compartment was first thinned commercially in 1974/75.

An internal road was used to separate the two treatments of (i) no burning and (ii) low intensity burning every 3 years. The initial burning treatment was carried out in July 1972, with the plantation at age 13 years, and further July burns were made in 1975, 1978 and 1981. Table 1 gives details of the fire intensities recorded. No crown scorch occurred during any of these burns.

The study is considered in three sections: effects on tree growth, effects on foliar nutrient levels and effects on soil nutrient levels.

Table 1. Fire intensity and fuel consumption in the 'burnt' treatment
The fire intensities were calculated after Byram (1959)

Characteristics of fire	1972	Year 1975	1978
Mean intensity (kW m^{-1})	145	85	52
Maximum intensity (kW m^{-1})	203	138	106
Fuel consumption (t ha^{-1})	5·6	7·1	6·0

Effects on Tree Growth

Stand Measurements

Five 0·1 ha plots were randomly established in the 'no-burn' area. A plot similar to each was then selected in the 'burn' area. The basis of this pairing was as follows:

(i) Pair 1: much less fuel suspension than average, higher incidence of *Passiflora foetida* (passion vine), greater species range in the understorey.

(ii) Pair 2: fairly grassy areas.
(iii) Pair 3: much grassier than average.
(iv) Pair 4: paired purely on stand characteristics of mean diameter and predominant height.
(v) Pair 5: much greater fuel suspension than normal, high incidence of couch grass.

From 1972, annual measures were commenced of diameter at breast height (DBH) and predominant height (PHT), defined as the average height of the tallest 50 trees ha^{-1}, measured as 1 tree per 0·02 ha units. Table 2 gives details of the measurements in 1972 and 1981.

Table 2. Stand details as measured in 1972 and 1981

The results are means of five plots per treatment; DBH/BA represents the quadratic mean DBH, and PHT is the predominant height, as defined in the text

Year	Treatment	Stocking (stems ha^{-1})	DBH/BA (cm)	Basal area (m^2 ha^{-1})	PHT (m)
1972	Unburnt	1016	18·8	28·1	15·0
	Burnt	1028	18·7	28·3	15·1
1981	Unburnt	704	23·9	31·7	20·4
	Burnt	732	23·8	32·4	20·2

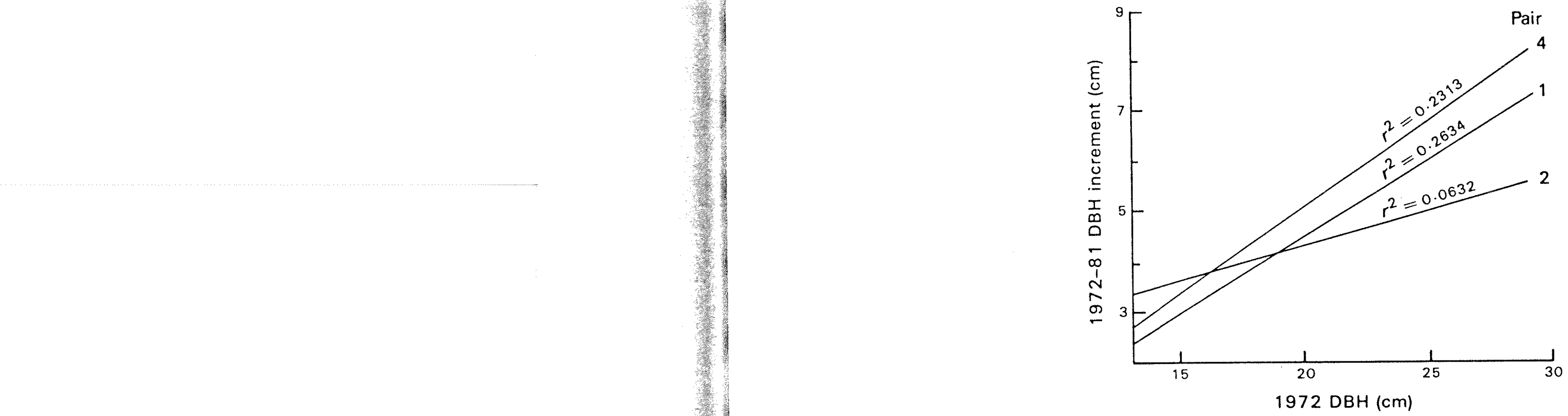

Fig. 1. Regression lines of DBH increment against original DBH for treatment pairs 1, 2 and 4.

Growth Analysis and Results

Graphical plotting of the raw DBH data suggested that diameter increment was linearly related to diameter. From a linear regression program, equations were obtained of the form $y = a + bx$, where y is the DBH increment for the period and x is the DBH at the start of the period, with a and b constants. Equations of this type were derived for each treatment pair for the increment period 1972–81. All the regression equations derived for the five plot pairs were highly or very highly significant and plots of residuals were acceptable in all instances. These equations were then compared between treatments, testing for differences in firstly slope and then intercept. For three of the plot pairs (1, 2 and 4) no significant differences in either were found. Pooled regression equations for each of these were then obtained; the regression lines are illustrated in Fig. 1. Therefore, no significant changes in diameter growth in these three plot pairs can be detected.

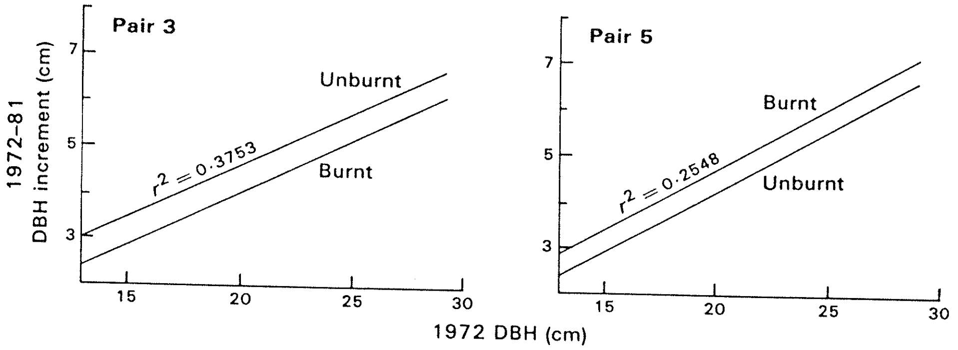

Fig. 2. Regression lines of DBH increment against original DBH for treatment pairs 3 and 5.

In the two other plot pairs (3 and 5), significant differences were found between intercepts, but there were no differences between slopes. By including a dummy variable for each plot pair an equation was obtained of the form $y = a + bx + cz$, where y and x are as before, z is the treatment variable, with a value of 1 for 'burnt' and 2 for 'unburnt', and a, b and c are constants. The regression lines of pairs 3 and 5 are illustrated in Fig. 2. Growth differences between treatments are significant in these two pairs. In pair 3, the unburnt plot has produced a significantly higher DBH increment for the period and the reverse has occurred in pair 5.

Table 3. Comparison of predominant height growth between treatments at establishment in 1972 with that in 1981

The results are means of five trees per plot, five plots per treatment; *, treatment differences significant at $P < 0{\cdot}05$; **, treatment differences significant at $P < 0{\cdot}01$

Year	Treatment	Predominant height (m) for pair:				
		1	2	3	4	5
1972	Unburnt	14·78	15·32	15·15	15·82	14·87
	Burnt	15·00	15·12	14·86	15·22	14·90
1981	Unburnt	20·76	20·36	20·78**	21·04	19·08*
	Burnt	20·18	20·47	19·44**	21·04	19·92*

The height growth data were examined by analyses of variance, comparing heights between treatment pairs firstly in 1972 and then in 1981. The results are presented in Table 3 and parallel the results found with diameter. In 1972, heights were similar but, in 1981, predominant height was significantly greater in pair 3 in the unburnt plot whereas the reverse applied in pair 5.

To summarize, significant differences in both diameter and height growth from 1972 to 1981 were detected between two of the treatment pairs. In one pair, growth was greater in the burnt treatment, while in the second pair, growth was greater in the unburnt treatment. In the three other plot pairs, diameter and height growth were similar for the period considered.

Effects on Foliar Nutrient Levels

Sampling

Foliar samples were collected at three-yearly intervals from 1972 to 1981 in early winter immediately prior to each burn. The sampling was designed to monitor changes in foliar nutrient levels that may have resulted from the prescribed burning treatments. A standard foliar sampling procedure was used. Five trees of near mean development were selected for sampling in each of the 10 plots. Where possible, the same trees were resampled on each occasion. Foliar samples comprised 200 fully expanded needles taken from the current season's growth flush on the branch nearest the north in the first major whorl from the tip of the tree.

Samples were oven-dried at 70°C as soon as possible after collection and ground to pass a 1·5 mm sieve. Nitrogen was determined by a modified micro Kjeldahl procedure with distillation and titration of ammonia (Bremner 1960). Other analyses were made on material dry ashed for 16 h at 450°C and taken up in dilute hydrochloric acid. Phosphorus was determined by the molybdenum blue spectrophotometric procedures (John 1970); potassium, calcium, magnesium and sodium were determined by atomic absorption spectrophotometry.

Table 4. Effects of burning treatments on foliar nutrients
The results are means of 25 analyses: 5 trees per plot by 5 plots per treatment. The values in parentheses are least significant differences (at $P = 0{\cdot}05$) for treatment means that differ significantly

Nutrient	Treatment[A]	Nutrient level (%) at sampling date:							
		May 1972		Apr. 1975		June 1978		June 1981[B]	
N	Bu	1·21		1·07		0·80		1·09	
	Ub	1·16		1·06		0·87		1·10	
P	Bu	0·067	(0·006)	0·055		0·051		0·059	
	Ub	0·075		0·056		0·054		0·062	
K	Bu	0·64	(0·075)	0·44	(0·060)	0·37		0·26	(0·030)
	Ub	0·75		0·58		0·42		0·30	
Ca	Bu	0·25		0·14		0·10		0·23	
	Ub	0·22		0·15		0·08		0·22	
Mg	Bu	0·20	(0·016)	0·12		0·12		0·16	
	Ub	0·18		0·13		0·12		0·15	
Na	Bu	0·045		0·054		0·030	(0·009)	ND	
	Ub	0·053		0·047		0·020		ND	

[A] Bu, burnt; Ub, unburnt; burning treatments were applied in July of each sampling year.
[B] ND, not determined.

Results

Major changes in foliar nutrient levels occurred between the samplings (Table 4). These changes are ascribed at least in part to a combination of factors such as seasonal differences affecting tree growth, nutrient availability and uptake and tree aging. There was a consistent decline in foliar potassium levels but for nitrogen, phosphorus, calcium

Table 5. Long-term effects of burning treatments on soil chemical properties

The results are means of analyses of 25 composite soil samples collected just prior to each burning. The values in parentheses are least significant differences (at $P = 0·05$) between values for burnt and unburnt treatments; asterisks indicate significant differences at $P < 0·05$

Property[A]	Depth (cm)	Treatment[B]	Soil content at sampling date:							
			May 1972		Apr. 1975		June 1978		June 1981	
pH	0–2·5	Bu	5·72	(0·12)	5·91	(0·17)	6·00	(0·15)	5·56	(0·13)
		Ub	5·80		5·96		5·90		5·51	
	2·5–7·6	Bu	5·70		5·90		6·00		5·46	
		Ub	5·76		5·90		5·88		5·42	
N	0–2·5	Bu	0·049	(0·006)	0·055	(0·008)	0·046	(0·006)	0·053	(0·006)
		Ub	0·047		0·051		0·049		0·057	
	2·5–7·6	Bu	0·044		0·047		0·044		0·044*	
		Ub	0·043		0·047		0·047		0·050*	
P tot.	0–2·5	Bu	44	(8)	60	(24)	38	(7)	33	(5)
		Ub	44		46		37		33	
	2·5–7·6	Bu	38		37		33		32	
		Ub	45		40		35		32	
Ex. K	0–2·5	Bu	0·055	(0·007)	0·055	(0·012)	0·049	(0·018)	0·047*	(0·011)
		Ub	0·050		0·059		0·060		0·061*	
	2·5–7·6	Bu	0·041		0·041		0·031		0·036	
		Ub	0·038		0·048		0·036		0·043	
Ex. Ca	0–2·5	Bu	2·03	(0·37)	1·95	(0·85)	1·75	(0·27)	1·84	(0·30)
		Ub	1·93		2·27		1·72		2·03	
	2·5–7·6	Bu	1·42		1·48		1·35		1·47	
		Ub	1·76		1·79		1·34		1·58	
Ex. Mg	0–2·5	Bu	0·70	(0·09)	0·68	(0·10)	0·73	(0·11)	0·76	(0·11)
		Ub	0·63		0·63		0·73		0·84	
	2·5–7·6	Bu	0·56		0·53		0·54		0·56	
		Ub	0·55		0·51		0·51		0·62	
Ex. Na	0–2·5	Bu	0·105*	(0·023)	0·073	(0·013)	0·049	(0·011)	0·044*	(0·015)
		Ub	0·073*		0·070		0·055		0·098*	
	2·5–7·6	Bu	0·085		0·068		0·048		0·045*	
		Ub	0·063		0·076		0·056		0·096*	
Ex. Al	0–2·5	Bu	0·072	(0·059)	0·043*	(0·080)	0·094	(0·129)	0·084	(0·085)
		Ub	0·128		0·136*		0·184		0·122	
	2·5–7·6	Bu	0·116		0·129		0·162		0·152	
		Ub	0·129		0·145		0·271		0·188	
Org. C	0–2·5	Bu	1·99	(0·26)	1·31	(0·22)	1·14	(0·18)	1·38*	(0·24)
		Ub	1·85		1·50		1·25		1·73*	
	2·5–7·6	Bu	1·68		1·26		1·03		1·08	
		Ub	1·69		1·36		1·11		1·27	

[A] Soil N and organic C content were measured as percentages, total P as ppm and the exchangeable cations as m equiv. %.

[B] Bu, burnt; Ub, unburnt.

and magnesium the levels dropped after the initial sampling but showed some increase at the last sampling. The nitrogen, calcium and magnesium levels are now at or above the putative acceptable levels. The phosphorus levels were at or below the accepted critical levels of 0·075% (Bevege and Richards 1971) at initiation of the trial, and all subsequent samplings have shown that the trees in these stands are phosphorus deficient.

Prior to the initial burn, foliar phosphorus and potassium levels were higher in the unburnt treatment whereas foliar magnesium levels were slightly higher in the burnt treatment. There were no significant differences between the initial nitrogen, calcium or sodium levels. Immediately prior to the second burn and thereafter phosphorus levels for both treatments had dropped to a common level. Potassium levels generally remained higher in the unburnt treatment. Prior to the third burn, sodium levels were higher in the burnt treatment.

Effects on Soil Nutrient Levels

Sampling

Soil samples were collected at the same time as foliar sampling was carried out, i.e. at three-yearly intervals from 1972 to 1981, to coincide with the burning cycle. Five sampling sites were selected to cover each plot and these positions permanently marked. Three soil cores 2·5 cm in diameter were taken at random from within 0·5 m of the peg at each site and separated into the surface 0–2·5 and 2·5–7·6 cm layers. The samples from each layer were bulked to give 10 composite samples per plot (5 sites by 2 depths).

Sampling immediately prior to each fire allowed only the long-term effects to be gauged. In order to provide some information on short-term effects, supplementary soil samples were collected within two weeks after the 1978 and 1981 burns for comparison with the pre-burn samples. The two layer depths were sampled according to the established procedure after burning in 1978 but only the surface 0–2·5 cm layer was resampled in 1981.

As soon as possible after collection the samples were set out for drying in an open glasshouse. After drying, the samples were passed through a 2 mm sieve. A range of chemical analyses was then undertaken on the fine earth fraction. Soil pH was measured with a glass calomel electrode on a 1 : 5 soil–water mixture. Nitrogen was determined by macro Kjeldahl digestion, ammonia distilled and titration against dilute H_2SO_4 (Bremner and Shaw 1958). Total phosphorus was extracted using constant boiling HCl and determined by molybdenum blue spectrophotometric procedure (John 1970). Exchangeable potassium, calcium, magnesium and sodium were determined by atomic absorption spectrophotometry on extracts made with 1 M neutral aqueous NH_4AC. Aluminium was extracted using 1 M aqueous KCl and determined by titration (McLean 1965). Organic carbon was determined by the Walkley and Black method (Jackson 1958).

Long-term Effects on Soil Chemical Properties

There was considerable variation between the samplings and between sampling depths, but no consistent differences can be attributed to the burning treatments (Table 5).

Between-sampling variation was minimal for pH and nitrogen and greatest for exchangeable sodium, aluminium and organic carbon. Since these differences are not only a reflection of seasonal changes but are also confounded with any differences in sampling or analytical detail that may have occurred between the samplings, no detailed interpretation was attempted.

Table 6. Short-term effects of burning on soil chemical properties

The results are means of analyses of 25 composite soil samples. The values in parentheses are least significant differences (at $P = 0·05$) between values for burnt and unburnt treatments; asterisks indicate significant differences at $P < 0·05$

Prop-erty[A]	Depth (cm)	Sample timing	Soil content in year: 1978		1981[B]	
pH	0–2·5	Pre-burn	6·00*		5·56*	
		Post-burn	6·22*		6·11*	
	2·5–7·6	Pre-burn	6·00	(0·08)	5·46	(0·06)
		Post-burn	6·02		—	
N	0–2·5	Pre-burn	0·046*		0·053*	
		Post-burn	0·050*		0·060*	
	2·5–7·6	Pre-burn	0·044*	(0·003)	0·044	(0·004)
		Post-burn	0·040*		—	
P tot.	0–2·5	Pre-burn	38*		33	
		Post-burn	44*		n.a.	
	2·5–7·6	Pre-burn	33	(4)	32	
		Post-burn	37		—	
Ex. K	0–2·5	Pre-burn	0·049*		0·047*	
		Post-burn	0·076*		0·063*	
	2·5–7·6	Pre-burn	0·031*	(0·009)	0·036	(0·006)
		Post-burn	0·052*		—	
Ex. Ca	0–2·5	Pre-burn	1·75*		1·84*	
		Post-burn	2·11*		2·23*	
	2·5–7·6	Pre-burn	1·35	(0·25)	1·47	(0·37)
		Post-burn	1·46		—	
Ex. Mg	0–2·5	Pre-burn	0·73*		0·76*	
		Post-burn	0·94*		0·97*	
	2·5–7·6	Pre-burn	0·54	(0·11)	0·57	(0·08)
		Post-burn	0·58		—	
Ex. Na	0–2·5	Pre-burn	0·050*		0·043*	
		Post-burn	0·076*		0·056*	
	2·5–7·6	Pre-burn	0·048*	(0·006)	0·044	(0·007)
		Post-burn	0·059*		—	
Ex. Al	0–2·5	Pre-burn	0·094		0·084	
		Post-burn	0·045		n.a.	
	2·5–7·6	Pre-burn	0·162	(0·088)	0·152	
		Post-burn	0·168		—	
Org. C	0–2·5	Pre-burn	1·14*		1·38	
		Post-burn	1·35*		n.a.	
	2·5–7·6	Pre-burn	1·03*	(0·09)	1·08	
		Post-burn	1·15*		—	

[A] Soil N and organic C content were measured as percentages, total P as ppm and the exchangeable cations as m equiv. %.

[B] n.a., not available because of insufficient sample.

Soil pH rose for both treatments from 1972 to 1975 and 1978 but dropped to below the original level in the 1981 sampling. Total phosphorus showed a possible general decline with time whereas the other elements were relatively stable or showed a less consistent trend.

Soil pH, total phosphorus and exchangeable sodium levels did not change noticeably with depth to 7·6 cm whereas nitrogen and exchangeable potassium, calcium and magnesium together with organic carbon showed generally lower levels below 2·5 cm.

The major effect of burning was expected to be confined to the top 2·5 cm layer. Significant effects of burning were detected in 1981. Organic carbon levels and exchangeable cations (potassium and sodium) were lowered by burning. These effects were less apparent in the earlier assessments. Similar though generally non-significant trends were apparent in the 2·5–7·5 cm layer.

It is concluded that, under the conditions of this trial, soil chemical properties of the surface of the A horizon have varied markedly between the samplings and that long-term differences are apparent between the treatments. The organic carbon levels and exchangeable cations on the soil surface are lower on the treatment regularly prescribed burnt.

Short-term Effects on Soil Chemical Properties

Comparisons of chemical properties of soil samples collected before and after burning in 1978 and 1981 are summarized in Table 6. For the 1978 sampling, all parameters (with the exception of exchangeable aluminium) increased in the surface after burning. Soil nitrogen decreased in the lower layer after burning. Total phosphorus, exchangeable sodium and organic carbon showed an apparent increase in both the surface and lower layers.

The 1981 pre- and post-burn comparisons of the surface 2·5 cm showed the same increase in soil exchangeable cations after burning. Soil pH and nitrogen of the soil surface increased to an even greater extent than in 1978.

While an increase in soil pH, nitrogen and exchangeable cations can be readily detected in the soil surface by sampling prior to and soon after burning, these increases are not evident if the sampling is delayed several years. The results of the pre-burn triennial sampling have in fact shown the reverse trend for soil exchangeable cations.

Discussion

Previous studies on the effect of fire on slash pine have found that, provided no crown scorch occurs, burning has no detectable effects on growth (Gruschow 1952; Johansen 1975; Byrne 1980). The results in this study are similar, with no observation of significant overall effects on growth resulting from the four prescribed burns. However, contradictory effects have been isolated for two of the treatment pairs. These differences are not considered to be directly linked to the burning treatments and appear to be closely related to the nutrient status of the sites, especially phosphorus nutrition. Phosphorus is the major nutrient limiting growth of exotic pines on the coastal lowlands of south-east Queensland (Young 1948; Richards 1958). The relationship between foliar phosphorus levels and growth has been defined by Bevege and Richards (1971), who have shown that where the foliar phosphorus level drops below 0·075% growth is reduced. Since trees in this experiment are suffering phosphorus deficiency, it could be expected that any effect of burning on the availability of phosphorus would be readily detected by changes in foliar phosphorus levels, and subsequently be reflected in tree growth. Chemical measures of soil phosphorus are considered less sensitive indicators of adequacy of, or changes in, phosphorus availability.

No long-term deleterious effect of regular low intensity burning is evident on either soil or foliar phosphorus levels. This contrasts with reports by Metz *et al.* (1961) and Alban (1977) who found that regular low intensity burning significantly increased levels of available soil phosphorus in the long term (10 years). McKee (1982) also reported long-term increases on the Coastal Plain pine sites following regular low intensity burns.

While differences in growth may be explained by changes in phosphorus nutrition, the effect of burning on soil or foliar phosphorus levels is more tenuous. If individual plot pairs are considered, the burning effects are confounded with site differences by the nature of the experimental layout.

Foliar analysis does not clearly reflect a long-term trend towards a lowering of the cation status of the soils of the burnt plots, despite the short-term increases due to burning. The putative acceptable level of foliar potassium is 0·40%. The low 1981 foliar potassium levels of 0·26% for the burnt plots and 0·30% in the unburnt plots are of some concern. Foliar analysis suggests that these stands are currently suffering multiple element deficiencies (phosphorus and potassium) and, while burning may be tending to reduce the decline in foliar phosphorus, it may be exaggerating the decline in soil potassium. This decline in soil reserves may be reflected eventually in the foliar levels and in subsequent growth.

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