INFLUENCE OF FUEL REDUCTION BURNING AND FERTILISATION ON THE GROWTH AND NUTRITION OF EUCALYPT SEEDLINGS

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GUINTO, D. F., XU, Z. H., HOUSE, A. P. N. & SAFFIGNA, P. G. 2002. Influence of fuel reduction burning and fertilisation on the growth and nutrition of eucalypt seedlings. The effects of long-term prescribed burning and N and P additions on tree seedling growth, nutrient concentration and nutrient uptake were evaluated. Two eucalypt species were grown under glasshouse conditions on potted topsoils collected from two recurrently burnt forests in subtropical Queensland. Annual burning for 42 years and biennial burning for over 20 years had no significant effect on biomass production of four-month-old *Corymbia variegata* and *Eucalyptus pilularis* seedlings respectively. However, annual burning did increase P concentration and uptake in *C. variegata* seedlings. Biennial burning decreased the N concentration but not N uptake of *E. pilularis* seedlings; P uptake was unaffected by burning. Biomass production of *C. variegata* seedlings grown on unburnt soil increased with added P and N + P; seedling growth on the annually burnt soil improved with N and N + P additions. In annually burnt soil, N is more limiting while in unburnt soil, P is more limiting. Only the combined application of N and P significantly increased the biomass production of *E. pilularis* seedlings, indicating that both nutrients are limiting growth irrespective of burning treatments. Long-term burning may have significant impacts on the N and P nutrition of recruited eucalypts of successive stands.

Key words: Prescribed burning - seedling growth - fertiliser application - *Corymbia variegata* - *Eucalyptus pilularis*

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GUINTO, D. F., XU, Z. H., HOUSE, A. P. N. & SAFFIGNA, P. G. 2002. Kesan pembakaran pengurangan bahan api dan pembajaan terhadap pertumbuhan dan pemakanan anak benih eukalip. Kesan pembakaran jangka panjang yang ditentukan dan tambahan N dan P terhadap pertumbuhan anak benih pokok, kepekatan nutrien dan kadar penyerapan nutrien dinilai. Dua spesies eukalip ditanam di bawah keadaan rumah kaca di dalam pasu berisi tanah atas yang diambil daripada dua hutan yang dibakar secara berulang-ulang di subtropika Queensland. Pembakaran hutan tahunan selama 42 tahun dan pembakaran dua tahun sekali selama lebih 20 tahun tidak memberikan kesan bererti terhadap pengeluaran biojisim masing-masing bagi anak benih *Corymbia variegata* dan *Eucalyptus pilularis* yang berusia empat bulan. Bagaimanapun, pembakaran tahunan menambah kepekatan dan kadar penyerapan P dalam anak benih *C. variegata.* Pembakaran dua tahun sekali mengurangkan kepekatan N tetapi tidak kadar penyerapan N dalam anak benih *E. pilularis.* Kadar penyerapan P tidak terpengaruh oleh pembakaran. Pengeluaran biojisim anak benih *C. variegata* yang ditanam di atas tanih yang tidak dibakar bertambah dengan penambahan P dan N + P; pertumbuhan anak benih di atas tanih yang dibakar setahun sekali diperbaik dengan N dan tambahan N + P. Di dalam tanih yang dibakar setahun sekali, N adalah lebih terhad manakala di dalam tanih yang tidak dibakar, P lebih terhad. Hanya campuran penggunaan N dan P meningkatkan dengan bererti pengeluaran biojisim anak benih *E. pilularis.* Ini menunjukkan bahawa kedua-dua nutrien merupakan pengehad pertumbuhan tanpa mengambil kira rawatan pembakaran. Pembakaran jangka panjang mempunyai kesan yang bererti terhadap pemakanan N dan P bagi eukalip pada dirian seterusnya.

Introduction

Low intensity, repeated fuel reduction burning is a widely used tool in the management of forests. The long-term cumulative changes in soil fertility resulting from this type of burning may influence the growth and nutrition of crop trees (McKee 1982, Waldrop *et al.* 1987, Guinto *et al.* 1996, 2001). However, a number of studies have shown little diameter growth response of overstorey trees to prescribed burning (Abbott & Loneragan 1983, Waldrop *et al.* 1987, Guinto *et al.* 1999); this may be because forest trees have nutritional mechanisms to cope with disturbances such as fires (e.g. mycorrhizae, within-plant recycling of nutrients). Since it is difficult to demonstrate growth response of a mature stand of trees to repeated prescribed fires, it is hypothesised that any soil nutrient changes arising from recurrent burning will be reflected in the biomass and nutrient uptake of successive stands. Young plants are more responsive to nutritional changes since they are in an active phase of growth and their nutrient requirements are met largely by uptake from soils (Grove *et al.* 1996). Thus, they may better reflect the cumulative changes in soil fertility associated with prescribed burning. For example, Wells (1971) conducted pot experiments with *Pinus taeda* (loblolly pine) seedlings and reported that repeated burning of varying frequencies over a 20-year-period had no effect on plant growth but increased P uptake while decreasing N uptake. On the other hand, McKevlin and McKee (1986) reported increased biomass, height, and N and P uptake of *P. taeda* seedlings grown on soils that had been burned annually for 33 years which they attributed to increased soil extractable P. Differences in early growth and nutrient uptake of tree species on unburnt and prescribed burnt soils may have important implications during forest regeneration and/or recruitment of seedlings of successive stands.

The objective of this study was to assess the effects of long-term prescribed burning and N and P fertilisation on seedling growth, nutrient concentration, and nutrient uptake of two eucalypt species from two contrasting sclerophyll forest types in subtropical Queensland, Australia.

Materials and methods

Site details and experimental design

Bauple State Forest (latitude 25° 48' S, longitude 152° 37' E) is approximately 260 km north of Brisbane, and situated at an elevation of about 60 m above sea level (asl). It is classified as a dry sclerophyll forest or an open forest (Specht 1970) dominated by spotted gum (*Corymbia variegata*, formerly *Eucalyptus maculata*) and grey ironbark (*E. siderophloia*). The understorey vegetation includes wattles (*Acacia* spp.), brush box (*Lophostemon confertus*), swamp box (*L. suaveolens*), red ash (*Alphitonia excelsa*) and lantana (*Lantana camara*) (Henry 1961). Average annual rainfall in the area is 1131 mm with over half of this occurring between December and March. There is a marked dry period from July to September. The topography is one of broad flat ridges separated by shallow gullies. Brown and red Kurosols cover most of the area, with red Kandosols appearing on some hill tops and gullies (Isbell 1996). The soils have loamy surface textures and are generally shallow with clay loam to clay textures at 30–40 cm depth. In 1952, two compartments were set aside by DPI (Department of Primary Industries) Forestry to investigate the long-term effects of two fire regimes, namely, no burning and annual burning in late winter or early spring (August to September). In 1973, periodic burning every two to three years was added as the third treatment in another compartment to simulate the Department's current routine prescribed burning practice in this forest type. There are six plots per treatment, with each plot measuring 100 × 40 m. It is important to note that the spatial arrangement of treatments (i.e. plots within a compartment receive only one burning treatment) has resulted in an experimental design which may be termed segregated (Hurlbert 1984), and is, therefore, not strictly randomised, an acknowledged limitation of the experiment. Nevertheless, within a compartment, plot locations were spread evenly and the average distance between two nearest neighbouring plots is about 0.7 km. This situation may weaken any spatial dependence of soil properties that could exist between neighbouring plots. One rationale behind the one compartment-one treatment approach to experimentation in this forest was to ensure protection of the experiment from unscheduled burns (Anonymous 1975), a major consideration at the time when prescribed burning techniques were in their infancy.

Due to logistical constraints, only three out of the six replicate plots of each treatment were sampled in this study. Plots were selected based on similarity of soil types and vegetation between compartments. Due to high fuel moisture content and/or unfavourable weather conditions, scheduled burns sometimes could not be achieved. At the time of sampling (September 1994), there had been 41 burns in the annually burnt treatment (last burned in 1992) and nine burns in the periodically burnt treatment (last burned in 1989). The control treatment has remained unburnt since 1946 when this forest land was first acquired by DPI Forestry. Prior to acquisition, however, the site would probably have been burned quite frequently by graziers while it was freehold land.

Peachester State Forest (latitude 26° 50' S, longitude 152° 53' E) is situated about 100 km north of Brisbane in the Sunshine Coast hinterland at an elevation of 137 m asl. It is a wet sclerophyll forest or a tall open forest (Specht 1970) dominated by blackbutt (*E. pilularis*). Other canopy tree species include *E. microcorys*, *E. resinifera*, *Lophostemon confertus* and *Syncarpia glomulifera*. The understorey vegetation is variable and species-rich, and in places it is dominated by grasses (e.g. *Imperata cylindrica* and *Digitaria ciliaris*), ferns (*Blechnum cartilagineum*) or shrubs (e.g. *Dodonaea triquetra*, *Hibiscus heterophyllus* and *Hovea acutifolia*). The average annual rainfall in the area is 1711 mm. The topography is undulating to rolling (2–16% slopes). The sandstone geology of the area has produced deep sandy soils having no perceptible increase in clay content to a depth of 60 cm. The soils are classified as red to yellow Kandosols (Isbell 1996).

The experiment was arranged in a split-plot design with fire regimes as the main plot treatment and slope position (lower and upper slopes) as subplot treatment. The plots were established in 1969 but the first burn was not conducted until about 1972, when all plots were burnt. Since that time, the fire treatments have included unburnt, biennial burning and quadrennial burning during late winter or early spring (August to September). There are three blocks, two of which are adjacent to each other while the third block is about 6 km away from the others. Plots in the two adjacent blocks measure 30 × 27 m while plots in the third block measure 40 × 20 m. The third block has soils with sandier texture and considerably less organic matter. They are classified as red Kandosols (Isbell 1996). There is also a marked change in the vegetation with the presence of grass trees (*Xanthorrhoea* spp.), banksias (*Banksia* spp.) and different grass species (*Entolasia stricta* and *Eremochloa bimaculata*) in the understorey. There is a total of 18 plots for the experiment. Like the dry sclerophyll site, high fuel moisture content and/or unfavourable weather conditions resulted in burns that were either poor or completely unsuccessful and vary from plot to plot. This illustrates the difficulty of applying quantitative levels of treatments as well as repeated application of treatments in designed fire experiments (Binkley *et al.* 1993). At the time of sampling (August 1994), there had been, on average, 10 burns in the biennially burnt treatment (last burned in 1991) and seven burns in the quadrennially burnt treatment (last burned in 1989).

Soil sampling, treatments and chemical analyses

Topsoil (0–10 cm, litter removed) samples were collected in August 1994 (wet site) and September 1994 (dry site) using a spade from six randomly selected points in each plot and bulked to produce a single composite sample per plot. For the dry sclerophyll site, only three out of six replicate plots were sampled, while for the wet sclerophyll site, all six replicate plots were sampled. In this latter site, the soil samples from the upper and lower slopes of plots with the same fire treatment were further bulked, effectively reducing the number of replicates to three.

The soil samples were sieved to < 2 mm and mixed thoroughly. Subsamples were taken for analysis of initial soil chemical properties (pH, total N, anaerobically mineralised N, acid-extractable and exchangeable K) as described in Guinto *et al.* (2001). The samples were then weighed (1.5 kg oven-dry equivalent) into plastic pots lined with polyethylene bags. For each forest type, factorial treatment combinations of burning frequency (unburnt and annual burning for the dry sclerophyll forest; unburnt and biennial burning for the wet sclerophyll forest) and fertiliser application (nil, 100 μg N g^{-1} soil, 100 μg P g^{-1} soil and 100 μg N g^{-1} soil + 100 μg P g^{-1} soil for both forest soils) were imposed. Thus, there were two separate experiments. Additions of N and P applied alone or in combination were employed to assess which nutrient(s) is/are limiting growth. Each treatment combination was replicated three times and pots were arranged in a randomised block design in the glasshouse (field replicates corresponded to potted soil replicates). Urea was used as the N source while sodium phosphate (Na_2HPO_4) was used as the P source. Both fertilisers were mixed thoroughly with the potted soil just prior to sowing the eucalypt seeds. For urea, application was split into two equal doses; one-half was applied prior to sowing and the other half applied one month after germination.

Ten seeds of *C. variegata* and *E. pilularis* were sown on their respective soil types in each pot. After germination, seedlings were thinned to two per pot and the plants were grown for four months. At harvest, leaves, stems and roots were separated, washed with deionised water, dried in the oven at 60 °C for 48 hours and weighed. The samples were then ground to pass a 0.5-mm sieve and analysed for N and P concentrations. Kjeldahl digestion was employed on all plant tissue samples. The digests were diluted to 100 ml. Nitrogen was determined on the Kjeldahl digests by steam distillation of a 20 ml aliquot and potentiometric titration (Bremner & Mulvaney 1982, Anderson & Ingram 1993). Phosphorus was determined colorimetrically using the ascorbic acid-molybdate method (Murphy & Riley 1962, Anderson & Ingram 1993). Sample absorbances were read at 880 nm using an LKB Novaspec II 4040 spectrophotometer. Data were presented as weighted average plant nutrient concentrations and as total biomass production (leaves + stems + roots).

Statistical analysis

Experimental data were subjected to factorial analysis of variance. The LSD (least significant difference) procedure was used for comparing treatment means at $p = 0.05$. Correlations between biomass, nutrient concentration and uptake were also calculated.

Results and discussion

Initial soil chemical properties

The initial chemical properties of topsoils from burnt and frequently burnt plots of both sites are shown in Table 1. At the dry sclerophyll forest site, more than 40 years of annual burning has resulted in greater acid-extractable P but no loss in total N. At the wet sclerophyll site, biennial burning has reduced total N and N mineralised during anaerobic incubation. The increase in acid-extractable P at this site was statistically insignificant. At both sites, exchangeable K seems adequate (> 0.2 cmol kg^{-1} soil) by agronomic standards (Bruce & Rayment 1982) and is also slightly higher in frequently burnt soils.

Biomass production, nutrient concentration and nutrient uptake

The p values from the analysis of variance of all measured plant parameters indicate that for both species, the effect of burning was not always significant while the effect of fertilisation was always highly significant (Table 2). For *C. variegata* seedlings, a significant fire by fertiliser interaction was observed in both total biomass and total N concentration (Table 2(a)). Thus, results are presented as a two-way table for these two parameters (Table 3) and as separate main effects of fire and fertiliser for the other parameters (Table 4). For *E. pilularis* seedlings, the interaction between prescribed burning and fertilisation was not significant for all parameters (Table 2(b)); therefore, results are presented as separate main effects of the two factors (Table 5).

Annual burning had no significant effect on the biomass production of *C. variegata* seedlings (Table 3). The response to nutrient additions, however, depended on whether the soil had been exposed to burning. Seedlings grown on the unburnt soil did not respond to the addition of N fertiliser but responded to the addition of P fertiliser and the combined application of these two nutrients

Table 1 Initial chemical properties of topsoils (0–10 cm) from the unburnt and frequently burnt plots of the (a) dry and (b)wet sclerophyll forests

Fire frequency	pH (1:5)	Acid-extractable P (mg kg^{-1})	Total N (%)	Anaerobically mineralised N (mg kg^{-1})	Exchangeable K (cmol kg^{-1})
(a) Dry sclerophyll site					
Unburnt	5.40 a	3.8 b	0.105 a	10.3 a	0.29 a
Annual	6.06 a	6.6 a	0.122 a	17.7 a	0.34 a
(b) Wet sclerophyll site					
Unburnt	5.56 a	2.8 a	0.183 a	20.2 a	0.22 a
Biennial	5.77 a	5.7 a	0.100 b	12.2 b	0.27 a

Extracted from Guinto *et al.*, 2001.
Within each site, column means with a common letter are not significantly different at p= 0.05

(Table 3(a)). On the other hand, seedlings grown on the annually burnt soil responded to N fertilisation. There appeared to be an increase in biomass with P fertilisation on burnt soil but this was not statistically significant. A significant biomass increase was noted for the combined N + P treatment. These results indicated that, in the annually burnt soil, N was more limiting (as burning depletes N through ammonium volatilisation) while in the unburnt soil, P was likely to be more limiting. The response to N addition under annual burning may be explained, at least partly, by the effect of the interaction of N and P availability. The increase in P availability in the burnt soil means that P limitation is reduced and so there is greater potential for a response to N. The full extent of this interaction is seen in the N + P treatment. The response to P fertilisation in the unburnt soil is readily explainable since many Australian forest soils are deficient in this element (McLaughlin 1996).

Table 2 Analysis of variance p values for the effects of fire frequency and fertiliser application on biomass production, N and P concentrations, and N and P uptake of (a) *Corymbia variegata* and (b) *Eucalyptus pilularis* seedlings

Source of variation	p values				
	Biomass	N concentration	P concentration	N uptake	P uptake
(a) *C. variegata* (dry sclerophyll species)					
Fire	0.3850	0.0329	0.0054	0.2550	0.0237
Fertiliser	0.0001	0.0003	0.0001	0.0007	0.0001
Fire × fertiliser	0.0092	0.0033	0.3003	0.2259	0.5876
(b) *E. pilularis* (wet sclerophyll species)					
Fire	0.4576	0.0417	0.1600	0.2715	0.5465
Fertiliser	0.0013	0.0016	0.0041	0.0009	0.0001
Fire × fertiliser	0.0842	0.1071	0.5327	0.1170	0.8092

Table 3 Influence of prescribed burning and fertiliser application on the (a) biomass production and (b) N concentration of *Corymbia variegata* seedlings

Fertiliser treatment	Fire frequency		
	Unburnt	Annual	Mean
(a) Biomass (mg pot^{-1})			
Nil	3247 d	4543 cd	3895
N	2805 d	10689 b	6747
P	8091 bc	7144 bcd	7618
N + P	20269 a	15916 a	18092
Mean	8603	9573	
(b) N concentration (%)			
Nil	1.02 b	0.87 bc	0.94
N	1.57 a	0.75 bcd	1.16
P	0.56 cd	0.71 bcd	0.64
N + P	0.49 d	0.56 cd	0.52
Mean	0.91	0.72	

Means within a row or a column followed by the same letter(s) are not significantly different at p = 0.05

Repeated prescribed burning might have increased "available" P in the long-term by possibly raising soil pH and thereby increasing the solubility of phosphate ions. A rise in one pH unit may increase phosphate solubility by tenfold (Lindsay & Vlek 1977). Thus, the growth response of *C. variegata* seedlings to P fertilisation of the annually burnt soil was less than that of the unburnt soil. Repeated burning, however, does not provide the same level of response as P fertilisation (McKevlin & McKee 1986). The long-term consequences of burning on P pools are yet to be quantified, although there is evidence of the short-term (< 40 years) benefits of burning in increased P availability and N fixation by understorey leguminous species (Guinto *et al.* 2000).

The N concentration of *C. variegata* seedlings grown on the unfertilised-unburnt soil was not significantly higher than that of seedlings grown on the unfertilised-annually burnt soil (Table 3(b)). The N concentration of seedlings in N-fertilised-unburnt soil was significantly higher than those of the rest of the treatment combinations. With the exception of this treatment, there was a trend towards decreasing N concentration in the unburnt and the annually burnt treatments with additions of N, P and N + P, most probably because of nutrient dilution effects (Jarrell & Beverly 1981). This indicates that dry matter production has proceeded more rapidly than the rate of nutrient uptake, resulting in lower N concentrations in the fertilised plants.

Although burning did not influence the biomass production of *C. variegata*, it increased total P concentration and P uptake, which reflects the beneficial effect of burning on plant P nutrition. McKevlin & McKee (1986) also observed increased P uptake of *P. taeda* seedlings in annually burnt soils. The total N uptake of seedlings did not differ between the unburnt and annually burnt treatments.

Relative to the check treatment, N fertilisation had no effect on the P concentration of *C. variegata* seedling while P and N + P additions significantly raised P concentration (Table 4). However, P concentration was significantly higher in the P treatment compared with the N + P treatment. As expected, the P and N + P fertiliser treatments resulted in significantly higher P uptake compared with the check treatment and N treatment.

Table 4 Main effects of prescribed burning and fertiliser application on P concentration, and N and P uptakes of *Corymbia variegata* seedlings grown on soils taken from dry sclerophyll forest[1]

Parameter	Factor					
	Fire frequency[2]		Fertiliser treatment[3]			
	Unburnt	Annual	Nil	N	P	N + P
P concentration (%)	0.06 b	0.10 a	0.03 c	0.03 c	0.15 a	0.10 b
N uptake (mg pot^{-1})	54.1 a	63.8 a	31.2 c	62.5 b	48.2 bc	94.0 a
P uptake (mg pot^{-1})	6.9 b	10.4 a	1.9 c	2.4 c	11.8 b	18.4 a

[1] Within either fire or fertiliser factor, row means with a common letter are not significantly different at p = 0.05

[2] Values averaged over all levels of fertiliser treatment

[3] Values averaged over all levels of fire frequency

Biennial burning did not significantly reduce the total biomass production of *E. pilularis* seedlings (Table 5) despite the fact that burnt soil has lower initial total N and N mineralised by anaerobic incubation. Similarly, N uptake was not significantly reduced. However, N concentration was significantly reduced and perhaps was a reflection of the better N nutrition of *E. pilularis* in the unburnt treatment. Phosphorus uptake was about the same under both burning treatments. There was an almost twofold increase in plant P concentration with biennial burning; however, this increase was not statistically significant.

Only the combined application of N and P significantly increased the biomass production of *E. pilularis* seedlings, indicating that both nutrients were limiting to growth at this site (Table 5). Phosphorus fertilisation led to greater biomass uptake than N fertilisation, although not a significant difference. Florence & Crocker (1962) also observed a response of this tree species to nutrient additions in a New South Wales forest soil only when N and P were applied in combination.

Table 5 Main effects of prescribed burning and fertiliser application on the biomass production, nutrient concentration and uptake of *Eucalyptus pilularis* seedlings grown on soils taken from wet sclerophyll forest[1]

Parameter	Factor					
	Fire frequency[2]		Fertiliser treatment[3]			
	Unburnt	Biennial	Nil	N	P	N + P
Biomass (mg pot^{-1})	8812 a	7344 a	3223 b	4278 b	8844 b	15970 a
N concentration (%)	1.22 a	0.94 b	1.09 b	1.60 a	0.75 b	0.89 b
P concentration (%)	0.08 a	0.14 a	0.02 b	0.02 b	0.22 a	0.18 a
N uptake (mg pot^{-1})	78.6 a	61.0 a	28.7 b	49.5 b	62.0 b	139.1 a
P uptake (mg pot^{-1})	9.6 a	8.4 a	0.5 c	1.0 c	13.5 b	20.9 a

[1]Within either fire or fertiliser factor, row means with a common letter are not significantly different at p = 0.05

[2]Values averaged over all levels of fertiliser treatment

[3]Values averaged over all levels of fire frequency

The results of this study suggest that, thus far, frequent long-term burning has had no deleterious impacts on seedling growth *per se*. Despite current evidence that burning in these forests does not significantly affect tree growth (Guinto *et al.* 1999), repeated and frequent fires may have significant longer-term impacts on the N and P nutrition of recruited eucalypts of successive stands.

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