Effects of fire retardant on soils of heathland in Victoria

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Foreword

Fire retardants have been used around the World in forest fire suppression operations for more than thirty-five years, particularly in places such as North America and the southern Mediterranean. In Victoria and other Australian States fire retardants have been used for approximately thirty years.

Retardant is typically used to help control wildfires when access by ground crews is difficult or unsafe, or when there will be lengthy travel times for crews to arrive at the fire. Retardants restrict the spread of fire and enable firefighters to control the extent of the area burnt. In an average year, Victoria experiences more than 600 wildfires in its parks and forests. These wildfires burn about 110 000 hectares. Retardant is used to assist with suppression on about ten percent of these fires.

Many different fire retardants are available commercially, but not all have been subject to rigorous environmental and health studies. Victoria, in common with other land management agencies in Australia, has adopted a position of only using those fire retardants that have been subjected to lengthy testing and approval by the United States Department of Agriculture (USDA).

In 1998, the Department sought advice from Victoria's State Chemistry Laboratory following local community concerns about water quality following the extensive (32 000 ha) Caledonia wildfire in Gippsland in January 1998. The State Chemistry Laboratory advised that the claims of risk to public health were not scientifically well-founded. Subsequent investigations of water quality in the Macalister River by the local water authority found no evidence of contamination by fire retardants. There were, however, significantly increased levels of suspended sediments thought to be due to the extensive surface flows resulting from heavy thunderstorm activity after the fire.

To assist Victorian park and forest managers to better evaluate the wildfire control options available, the Department in 1999 commissioned the CSIRO Division of Forestry and Forest Products to assess the effectiveness and environmental risk associated with the use of retardants. The resultant report - *Assessment of the effectiveness and environment risk of the use of retardants to assist in wildfire control in Victoria* (DSE Fire Research Report No. 50, February 2000) - represented the most detailed examination of the subject in an Australian context.

The CSIRO report stated "We consider that the aerial application of long-term fire retardant which meets or exceeds the USDA Forest Service performance standard is essential for efficient fire fighting in the Victorian environment…"

The CSIRO review did, however, recommend that further research into the impact of the use of retardant on specific Australian ecosystems be conducted.

In response to the CSIRO findings, the Department further strengthened its management of the use of fire retardants. In addition, it set up a specific research program to examine the impact of long-term fire retardant on three elements of eastern Australian heathland communities, namely the vegetation, invertebrates and soils. This report derives from one of those studies.

More generally, Victoria's *Code of Practice for Fire Management on Public Land* sets out principles for environmental care that underpin all fire management activities. The application of chemicals in wildfire suppression does have some environmental impacts, as does the building of control lines (with either bulldozers or hand-tools) and backburning—but so too does uncontrolled wildfire. Managers of park and forest fires have to make regular judgements about these matters; often in highly dynamic situations. The information derived from these studies should further assist land managers in the judgements they are required to make when managing wildfire suppression operations.

Gary Morgan AFSM

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December 2003

Fire Research Reports derived from this investigation are:

No.	Title
68.	Effects of fire retardant on vegetation in eastern Australian heathlands: a preliminary investigation
69.	Effects of fire retardant on heathland invertebrate communities in Victoria
70.	Effects of fire retardant on soils of heathland in Victoria

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Summary

Fire retardants have been used operationally for the control of wildfires in Victoria's parks and forests since 1967. One of the most effective retardants used is Phos-Chek D75-R (Phos-Chek), which contains ammonium sulphates, ammonium phosphates, guar gum, iron oxide and performance additives (CSIRO 2000). While the use of this product in natural environments has been approved by the United States Department of Agriculture, a recent review by CSIRO (2000) identified that no experiments have been conducted to examine the effects of this retardant specifically on native flora and fauna in Australia. A study was therefore initiated in 2000 by Fire Management of the then Department of Natural Resources and Environment to assess the effects of fire retardant on vegetation, soil chemistry and surface-active invertebrates in fire-prone heathland communities near the coast at Marlo and in the Victoria Valley of the Grampians. The impact of retardant on soil chemistry is reported here, the effects on vegetation (Bell 2003) and invertebrates (Collett & Schoenborn 2003) are reported separately.

The application of retardant at rates required for effective control of fire (1.5 L/m^2 of a solution of 14% Phos-Chek) equate to broadcast applications of elemental nitrogen, phosphorus and sulphur of approximately 340, 90 and 330 kg/ha respectively. Monitoring of properties of surface soils to a depth of 20 cm was conducted at 2, 6 and 12 months after treatment and provided an insight into the immediate and short-term effects on properties of Podosols at these sites. The impact of Phos-Chek on surface soils at Marlo and the Grampians can be summarised as:

- Retardant decreased soil acidity (pH) by up to 0.5 units to pH 4.8 at Marlo and by 0.3 units to pH 4.9 at the Grampians site. The effect on soil pH was still evident after 12 months and further soil monitoring is required to determine the long-term impact in the soil profile.
- Soil salinity increased immediately at both sites, this was followed by a rapid decline to pre-treatment values within 12 months. Changes in salinity were related mainly to increases in soluble sulphate from the retardant.
- The impact of retardant on total carbon and nitrogen in the soil was relatively minor and within the range of natural variation of these elements in the surface soil at both sites.
- Levels of readily available or labile forms of nitrogen increased about three-fold at Marlo and nearly ten-fold at the Grampians. This substantial increase in labile nitrogen was of short duration and levels declined rapidly to background values after 12 months.
- A significant five-fold increase in labile phosphorus was found in the surface soil after 12 months. At Marlo, the application of retardant progressively increased extractable phosphorus in the surface soil from 2 to 9 mg/kg over 12 months. In contrast, a rapid increase in extractable phosphorus from 2 to 36 mg/kg was observed after 2 months at the Grampians site followed by a decline to 10 mg/kg after 12 months. These results indicate that a large proportion of the phosphate applied in retardant has been leached into the subsoil.
- Retardant applied at the highest rate caused a three-fold increase in labile sulphate after 2 months at Marlo followed by a rapid decline to background levels. In contrast, labile sulphate increased nearly twenty-fold after 2 months at the Grampians site followed by a rapid decline to background levels. Results indicate that sulphate applied has leached rapidly into the subsoil increasing the level of soluble salts stored in the soil profile.

This study showed some important short-term changes in soil properties in terms of salinity, pH and labile forms of nitrogen, phosphorus and sulphate. There is also evidence of more long-term changes in extractable phosphate and, to a lesser extent, soil pH. Monitoring of soil properties was limited to the surface soil (0–20 cm) but results indicate significant leaching of retardant into the subsoil. It is expected that the elevated levels of soil phosphate in particular could have a long-term impact on the growth and composition of heathland vegetation at these sites. It is therefore important to determine the accumulation of phosphate in the soil profile at least to the maximum depth of the root zone and the changes this may have induced in the vegetation. It is recommended that these experimental sites be maintained to allow further monitoring of soil profiles and vegetation in 2005, four years after application of the retardant. This should provide a better insight into the longer-term impact of retardant on soil chemistry of these Podosols and the availability of nutrients to plants on these heathlands.

Introduction

Victoria has some of the most bushfire-prone environments in Australia and there is a heavy reliance by authorities responsible for the control of wildfire on intensive fire suppression activities including the application of fire retardant chemicals by aircraft. Fire retardants have been used operationally in Victoria's parks and forests since 1967 and today are used in approximately 10% of all fires on public lands. Retardants are particularly useful in slowing the spread of fires in remote, inaccessible terrain, thus allowing time for the construction of control lines. The retardant commonly used in Victoria is Phos-Chek D75-R (hereafter referred to as Phos-Chek), which contains ammonium sulphates, ammonium phosphates, guar gum, iron oxide and performance additives (CSIRO 2000). While the product is approved for use in natural environments by the United States Department of Agriculture, a review by CSIRO (2000) of the effectiveness and environmental risks associated with the use of Phos-Chek pointed out that no experiments had been conducted in Australia to examine the impact of this retardant on the native forest ecosystems.

Only one previous study, by Bradstock et al. (1987), has investigated the effect of ammonium sulphate on Australian plants. This study indicated significant short-term effects, including widespread leaf death in trees, shrubs and ground cover plants. While it may be argued that the latter effect is comparable to the effects of fire, there is concern that the resulting increase in nitrogen, phosphate and sulphates in the soil may have a significant impact on nutrient cycles and flora and fauna of native ecosystems. Several studies have recorded increases in growth and changes in the composition and abundance of species following the application of nitrogen and phosphate fertilisers at rates similar to the operational use of fire retardant (Bauhus et al. 1999; Grove 1988; Heddle & Specht 1975; Stoneman et al. 1997). This issue is of particular importance in vegetation communities that have adapted to low nutrient environments or have a high conservation value. In response to the review by CSIRO (2000), Fire Management Branch of the-then Department of Natural Resources and Environment initiated a multidisciplinary study to assess the effects of fire retardant on vegetation, soil chemistry and surface-active invertebrates in fire-prone heathland communities near the coast at Marlo and in the Victoria Valley of the Grampians. The aim of this part of the study was to determine the immediate and short-term responses of fire retardant on the fertility of surface soils at the two heathland sites.

Materials and methods

Study sites

Two study sites were selected in heathland areas in Victoria. One was located at the Marlo airstrip (37º 47' 26.58" S, 148º 36' 28.99" E) at an elevation of 20 m on a flat aspect approximately 20 km south-east of Orbost in East Gippsland. The second site was located near the airstrip in the Victoria Valley in the Grampians (37º 11' 5.09" S, 142º 20' 27.90" E) at an elevation of 220 m on a flat aspect, approximately 25 km west of Halls Gap in western Victoria.

Vegetation at the Marlo site is generally described as a 'wet coastal heathland assemblage' with the dominant overstorey species including *Leptospermum continentale)* Joy Thomps. (Prickly Tea-tree), *Allocasuarina paludosa* Sieber ex Spreng. (Scrub Sheoak) and *Bossiaea prostrata R. Br.* (Creeping Bossiaea), while dominant understorey species include *Panicum simile* Domin. (Hairy Panic) and *Poa clelandii* Vickery (Tussock Grass). Plant heights range from 85 cm (*A. paludosa*) to 70 cm (*L. continentale*) while cover estimates for the dominant overstorey species range from 1% to 50% on the Braun Blanquet scale (Kent & Coker 1992). Further details on the vegetation at the Marlo site are reported in Bell (2003).

Soils at the Marlo study site are part of the coastal dune land system comprising highly-sorted sands from recent maritime and aeolian deposits. Soil profiles of the inter-dune depressions show an accumulation of organic matter in the predominantly sandy A1 horizon, a bleached A2 horizon over a dense illuviated organic B horizon of sandy loam. This impeding layer results in perched water tables and periodic waterlogged conditions are common. These soils are generally classified as humus podzols or semi-aquic Podosols based on the Australian Soil Classification (Isbell 1996).

Vegetation at the Grampians study site is generally described as a 'sandy heathland assemblage' with the dominant overstorey species including *Leptospermum continentale*, *L. myrsinoides* Schltdl. (Heath tea-tree), *Banksia marginata* Cav. (Silver Banksia), *Brachyloma daphnoides* Sm. Benth. (Daphne Heath) and *Allocasuarina paludosa*, while dominant understorey species include *Hypolaena fastigiata* R. Br. (Tassle Rope-rush) and *Lomandra multiflora* R. Br. (Many-flowered Mat-rush). Plant heights range from 115 cm (*A. paludosa*) to 80 cm (*B. marginata*) while cover estimates for the dominant overstorey species range from 1% to 25% on the Braun the Blanquet scale. Further details on the vegetation at the Grampians site are reported in Bell (2003).

Soils of the Grampians study site are part of the flat plains and swamps of the Moora Valley derived from the alluvial riverine deposits at the upper reaches of the Glenelg River (Sibley 1967). Soil profiles are characterised by sandy A1 horizons showing low to moderate accumulation of organic matter, grading to a bleached A2 horizon over an organic sesquioxide pan changing to a mottled sandy clay B horizon. Periodic waterlogging is common in areas with shallow A horizons where heath is generally the dominant vegetation. These soils are generally classified as humosesquic Podosols (Isbell 1996).

The Marlo study site was burned once in the mid-1960s and thereafter the heath was slashed occasionally as a fire prevention measure until 1985–86 (G. McCarthy pers. comm. 2002). Since fire records commenced in 1939, the Grampians study site has been prescribed burned twice: in 1963 and 1985 (M. Wouters pers. comm. 2002).

Design and installation of trials

At the Marlo study site, a randomised block design with five replicates x five treatments was used while, at the Grampians study site, a Latin square design was used with five replicates x five treatments. The five treatments applied at both sites in the study were:

Treatment One:	'untreated control'
Treatment Two:	water at 1.0 L m^2; ('water only')
Treatment Three:	fire retardant at 0.5 L m^2 ('low retardant')
Treatment Four:	fire retardant at 1.0 L m^2 ('medium retardant')
Treatment Five:	fire retardant at 1.5 L m^2 ('high retardant')

The retardant was prepared at the recommended mixing ratio of 0.144 kg of Phos-Chek powder per litre of water (CSIRO 2000). Treatments Three (low retardant), Four (medium retardant) and Five (high retardant) represent the range of application rates used operationally in fire situations in Victoria. Treatment Two consisted of water only and provides a direct comparison with the three fire retardant treatments. Plots at both sites comprised a 20 m x 20 m treated area with an internal measurement/sampling plot of 10 m x 10 m to minimise the influences from adjacent treatments or areas external to the study boundaries. The use of internal sampling plots with comparatively large buffers also reduced the risk of retardant contamination from adjacent plots during waterlogged conditions. Treatments at the Marlo site were applied within a five-day period between 2 and 6 March 2001, while treatments at the Grampians site were applied within a six-day period from 29 March to 3 April 2001.

Soil sampling

Composite soil samples were collected for two horizons (0–10 cm and 10–20 cm), each comprising 20 soil cores (approx. 5 cm diameter) taken along two diagonal transects per plot. A total of 50 soil samples per trial were collected at each sampling time. A sampling frequency of 2, 6 and 12 months after treatment was selected to provide an indication of the immediate impact of the application of retardant and an estimate of the change with time up to 12 months post-treatment. Soil conditions at the 2- and 6-monthly collections were dry and moist respectively. However, both sites were flooded at the final 12-month collection in March 2002.

Soil analysis

CSIRO (2000) reports that Phos-Chek retardant contains mainly di-ammonium sulphate (>65% W/W) and mono- and di-ammonium phosphates (>20% W/W) in combination with guar gum (thickening agent, < 10% W/W), iron oxide (red dye, <1% W/W) and 'performance' additives (<5% W/W). Treatment with retardant can therefore be expected to affect soil pH and salinity as well as levels of nitrogen (N), phosphorus (P) and sulphur (S) in soil profiles.

Soil tests selected for this investigation include pH, salinity—in terms of electrical conductivity (EC), total carbon as well as total and mineralisable N, extractable P and S. Soils were air-dried in the laboratory and sieved past 2 mm in preparation for chemical analysis. A sub-sample was finely-ground past 0.5 mm for analysis of total carbon and total N by the Dumas dry-combustion method using a CHN-2000 analyser (LECO Corporation). Soils were also analysed for pH_{water} (1:5), EC (1:5), extractable P (Bray-P) and extractable S (0.01M calcium phosphate). Soil testing was based on standard methodologies as outlined in Rayment and Higginson (1992) with minor modifications. Extractable Bray-P was determined using a soil/extractant ratio of 1/10 and an extraction time of 10 minutes. Likewise, an extraction time of one hour was used for the determination of extractable S.

Extraction of N with hot potassium chloride provides an assessment of mineralisable or 'labile' soil N potentially available for plant uptake (Wang et al. 1996). Soil was refluxed overnight (17 hrs) in hot KCL at 100ºC. N in the soil extracts was determined colorimetrically based on the indophenol reaction as described by Rayment and Higginson (1992).

Changes in soil properties in response to applications of fire retardant were examined with reference to the control and water-only treatments at 2, 6 and 12 months after treatment using the appropriate analysis of variance procedures for the design of the trials (Statview 1998).

Results

The treatments with Phos-Chek dissolved in water (14 % W/V) and applied at rates of 0.5, 1.0 and 1.5 L/m^2 equate to applications of fertiliser N, P and S commonly used to correct nutrient deficiencies and stimulate growth in plantation forestry (Table 1). The principal ingredients of Phos-Chek are ammonium sulphates and phosphates. The retardant also includes guar gum (approx. 34% carbon), a thickening agent containing mainly galactose and mannose sugars. Therefore applications of retardant will also add readily available sources of carbohydrates to the soil.

Table 1 Applications of carbon, nitrogen, phosphorus and sulphur in fire retardant solutions (14% Phos-Chek W/V) applied over heathland vegetation at Marlo and the Grampians

	Rate of application of Phos-Chek (L/m^2)			
Nutrient change[1]	**0.5**	**1.0**	**1.5**	**Maximum[2] (mg/kg soil)**
Carbon (kg/ha)	24	48	71	30
Nitrogen (kg/ha)	112	225	337	141
Phosphorus (kg/ha)	31	63	94	39
Sulphur (kg/ha)	109	219	328	137

Notes:

1. Potential change in concentration of nutrients in the 0–20 cm layer of the soil profile: assumes a uniform broadcast application, all retardant is leached into the soil, and a soil bulk density of 1.2 Mg/m^3.
2. Maximum expected change in the levels of these nutrients in soil (0–20 cm) were estimated for the highest rate of application of fire retardant.

Average soil properties for the three sample collections of the control plots provide a comparison of soil characteristics between the two heathland sites. Surface soils at Marlo and the Grampians have similar pH. However the pH of the 10–20 cm layer was slightly higher at Marlo (Table 2). This site also showed a higher level of soluble salts (EC) compared with the Grampians site. Soil carbon, total and mineralisable N and levels of extractable P and S were consistently higher at the Marlo site. Results indicate greater accumulation of soil organic matter and carbon (C) in the soil at Marlo and this was also reflected in the higher C/N ratios (C/N 19) compared with the Grampians (C/N 15). Levels of mineralisable N, extractable P and S were low but typical for coastal sandy podzols with low levels of clay minerals; nutrient availability in these soils is therefore mainly associated with soil organic matter.

Table 2 Soil pH, salinity, total carbon and nitrogen, mineralisable nitrogen and extractable phosphorus and sulphur in surface soils at Marlo and the Grampians

Site	Layer (cm)	pH	EC (μS/cm)	Total C (g/kg)	Total N (g/kg)	Min. N (mg/kg)	Extr. P (mg/kg)	Extr. S (mg/kg)
Marlo								
	0-10	5.2	115	21	1.1	16	1.5	11
	10-20	5.4	93	15	0.8	10	1.3	10
Grampians								
	0-10	5.2	21	9	0.6	9	0.6	3
	10-20	5.2	16	6	0.4	5	0.4	2

Effects of fire retardant on soils

Soil pH

Treatment with retardant decreased pH at the Marlo site by 0.1 to 0.3 units depending on the rate of application (Figure 1). Initially, changes in pH were mainly in the surface soil, but decreases of up to 0.5 units were measured to a depth of 20 cm after 12 months. In contrast, 2 months after treatment at the Grampians site, a significant increase in pH of 0.3 units in the surface soil and a decline in pH of 0.4 at 20 cm depth was observed. After 12 months soil pH in the retardant treatments remained lower by 0.2 to 0.3 units compared with the untreated plots.

Salinity

Applications of retardant did not significantly affect soil salinity at Marlo mainly because of the already high levels and large variability in soluble salts across the site (Figure 1). Closer examination of the data showed that levels of soluble salts were consistently higher in blocks D (330 μS/cm) and E (90 μS/cm) compared with the range of average EC levels in blocks A, B and C (50 to 53 μS/cm). When data from block D was omitted from the analysis, the increase in salinity due to retardant was significant statistically at 2 months but not at subsequent sample collections.

In contrast, background levels of salinity at the Grampians were low and relatively uniform across the site and treatment with fire retardant increased the levels of soluble salts substantially at this site (Figure 1). This increase in soluble salts was of short duration and, while there was still evidence of elevated salt levels after 12 months (Figure 1), differences between control and fire retardant treatments were no longer statistically significant.

The application of retardant and, in particular, the substantial addition of soluble ammonium sulphates and, to a lesser extent, phosphates to the soil (see Table 1) did have an immediate impact on soil salinity. Changes in EC were primarily related to the increase in levels of extractable S (r^2 0.91) at the Grampians where the background levels of soluble salts in soil were low (Figure 2). In contrast, changes in EC were not strongly correlated with extractable S (r^2 0.52) at Marlo because of the higher and more variable background in soil salinity at this site. While the increased levels of mineral N and extractable P would have contributed to the salinity in these soils, inclusion of these parameters into a multiple regression analysis only improved the fit of the model marginally.

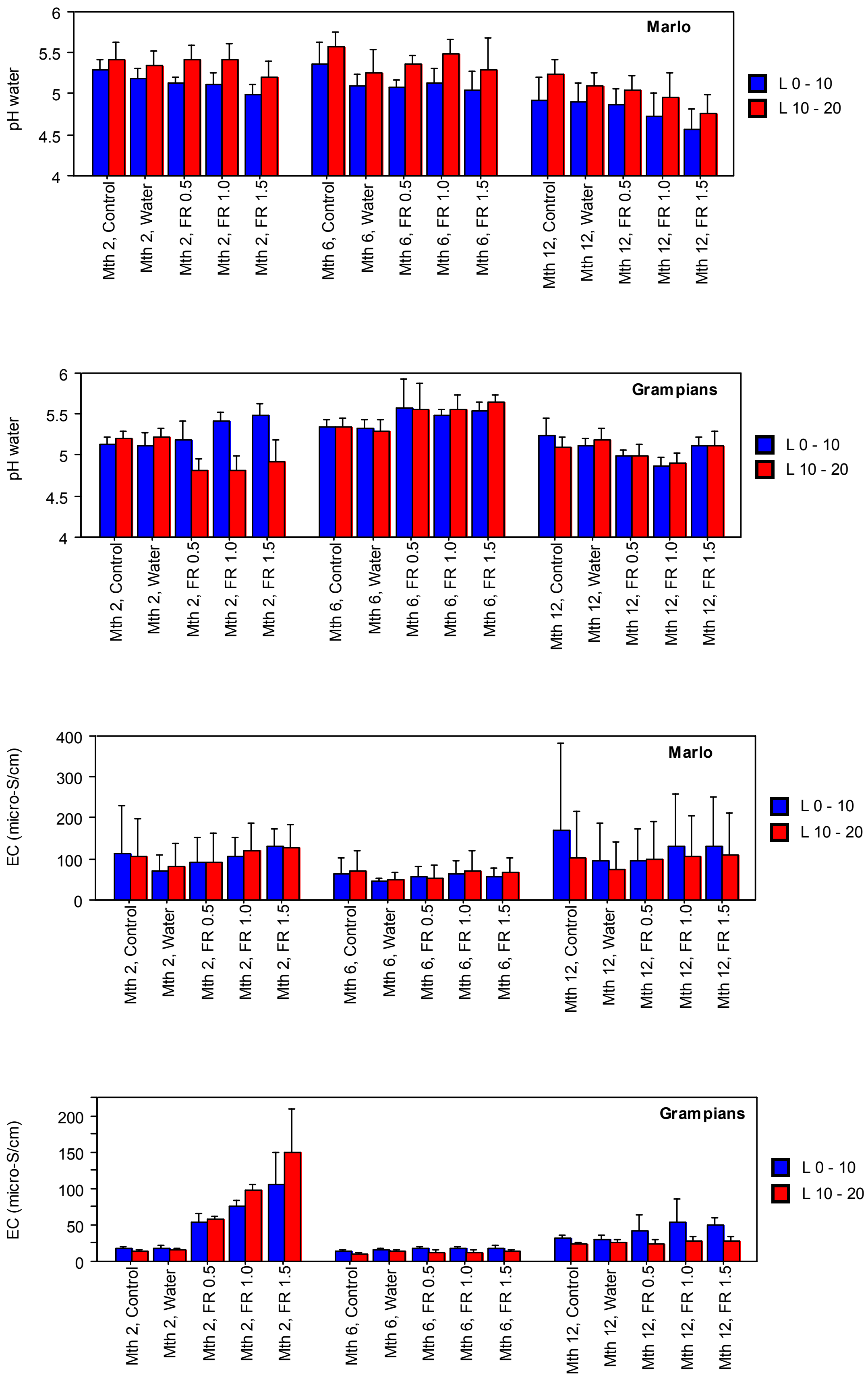

Figure 1 Changes in soil pH and salinity (EC) in response to applications of fire retardant at Marlo and the Grampians

Bars indicate standard deviations

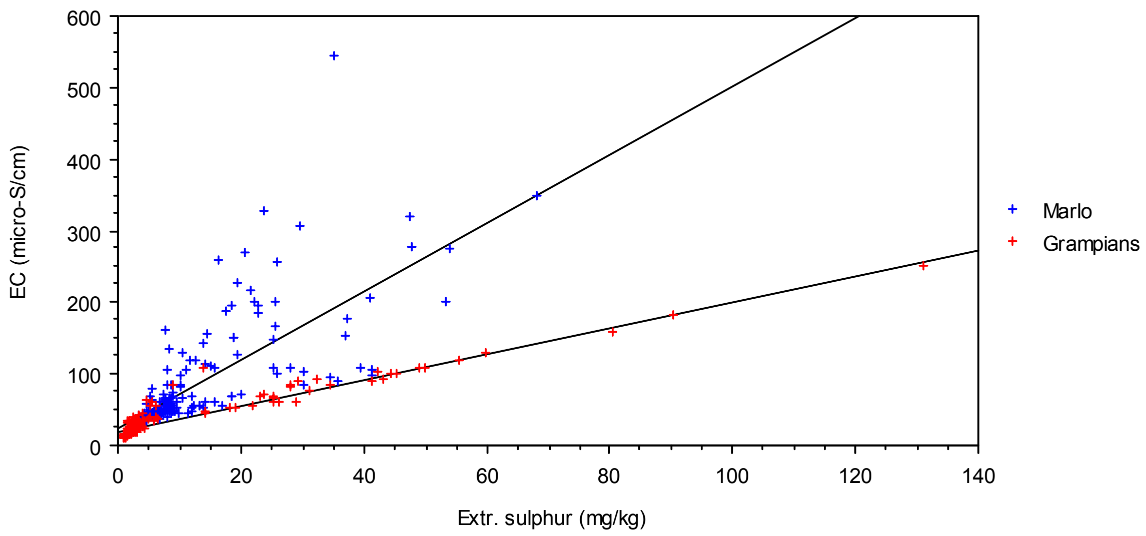

Figure 2 Relationships between soil salinity (EC 1:5) and extractable sulphur in soils treated with fire retardant at Marlo and the Grampians

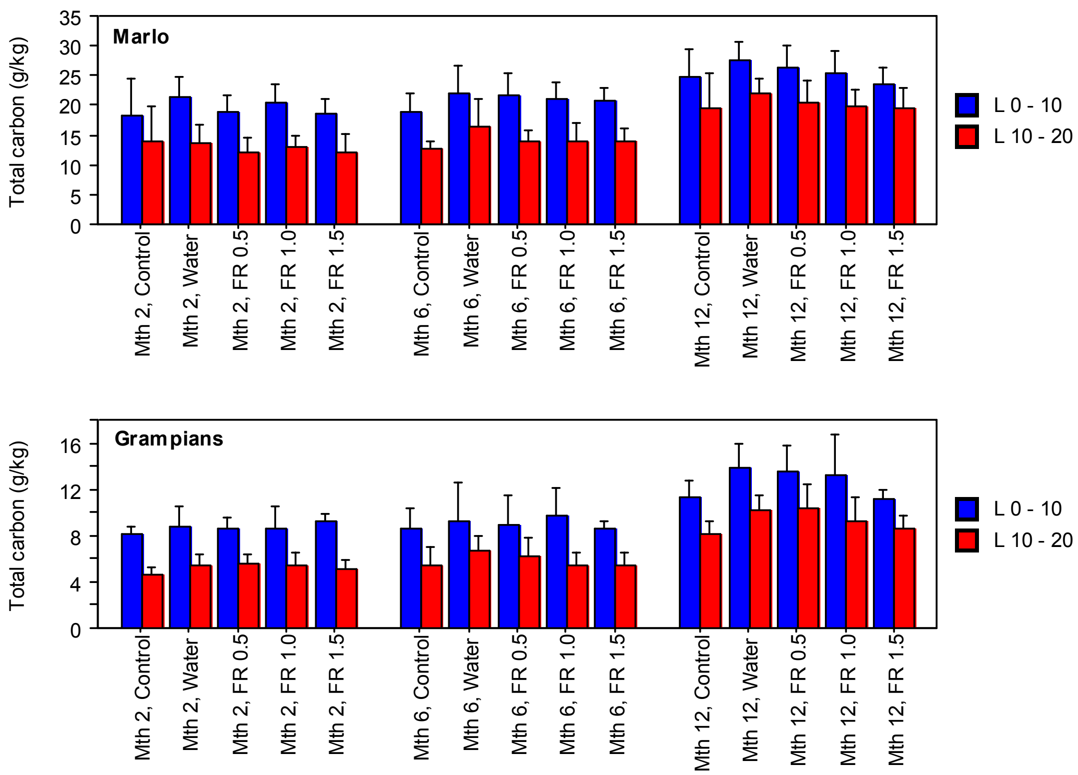

Figure 3 Total carbon in soils treated with fire retardant at Marlo and the Grampians
Bars indicate standard deviations.

Total carbon

Applications of retardant did not affect the levels of total carbon in soils at either Marlo or the Grampians sites (Figure 3). The addition of carbon from guar gum in the retardant was small and was estimated to raise the level of carbon between 0.01 and 0.03 g/kg of soil to a depth of 20 cm (Table 1). This compares with average levels of carbon in untreated surface soils of 21 g/kg (± 5.2 g/kg standard deviation) at Marlo and 9 g/kg (± 1.9 g/kg standard deviation) at the Grampians.

Levels of carbon in soils were significantly higher at the final collections at both sites but, as these increases were measured across all treatments, this change was unlikely to be due to the fire retardant. Both sites were flooded at the final collection and it is suggested that this may have raised levels of dissolved organic carbon in surface soil from illuviated humus sources in the subsoils of these podzols.

Total and mineralisable nitrogen

Treatment with fire retardant did not change the levels of total nitrogen in soils at Marlo and the Grampians (Figure 4). The maximum amount of nitrogen as ammonium phosphates and sulphates in Phos-Chek added to the surface soil was estimated at 337 kg/ha (Table 1). Assuming all applied nitrogen entered the soil, the expected maximum change in soil N to a depth of 20 cm was estimated at 0.14 g/kg. This compares with average levels of total nitrogen in untreated surface soils of 1.08 g/kg (± 0.33 g/kg standard deviation) at Marlo and 0.58 g/kg (± 0.15 g/kg standard deviation) at the Grampians. Therefore the potential change in total N due to the addition of fire retardant was within the range of natural variability at each site.

Like total carbon, levels of total N in the soils increased at the final sample collection at both sites (Figure 4). It is suggested that this was associated with the flooded conditions at the sites and the rise in dissolved organic matter from deeper in the soil profile. This is consistent with the uniformity in C/N ratios between soil collections at both sites, indicating that soil organic matter at the last collection was most likely derived from the same source in the soil profile (Figure 5). It should also be noted that the addition of nitrogen as ammonium salts in fire retardant did not affect C/N ratios in soils at either Marlo or the Grampians.

Treatment with retardant containing ammonium salts at rates equivalent to broadcast applications of N at rates of 112, 225 and 337 kg/ha (see Table 1) did have considerable impact on the levels of mineralisable or labile nitrogen in the surface soils at both sites (Figure 4). At Marlo, concentrations of labile N in the 0–10 cm and 10–20 cm layers increased to 47 mg/kg and 29 mg/kg respectively after 2 months but decreased thereafter. At 6 months, levels of N were still elevated for the highest rate of retardant but the differences between control and any of the fire retardant treatments were no longer significant after 12 months.

At the Grampians site, where background levels of labile N were low (Table 2), treatment with retardant increased levels in the surface soil (0–10 cm) from 12 mg/kg in control plots to 46, 81 and 116 mg/kg for rates of 0.5, 1.0 and 1.5 L/m^2 of Phos-Chek solutions respectively (Figure 4). Changes in labile N in the next soil layer (10-20 cm) were less in magnitude but equally significant. Even at the highest rate of application, levels of mineral N in the surface soil declined rapidly to 23 mg/kg after 6 months and 19 mg/kg after 12 months.

Two months after application of fire retardant at rates of 0.5, 1.0 and 1.5 L/m^2, labile N content of the soil to a depth of 20 cm was estimated at 2, 18 and 54 kg/ha at Marlo and 59, 131 and 215 kg/ha at the Grampians respectively. The initial impact of retardant appears to have been significantly greater at the Grampians site in terms of changes in labile N in the soil. A high proportion of N applied in the retardant (see Table 1) was recovered in the soil representing 53%, 58% and 64% of the amounts applied at the Grampians. In contrast, the amounts of N recovered after 2 months were considerably lower, namely 2%, 8% and 16% respectively at the Marlo site.

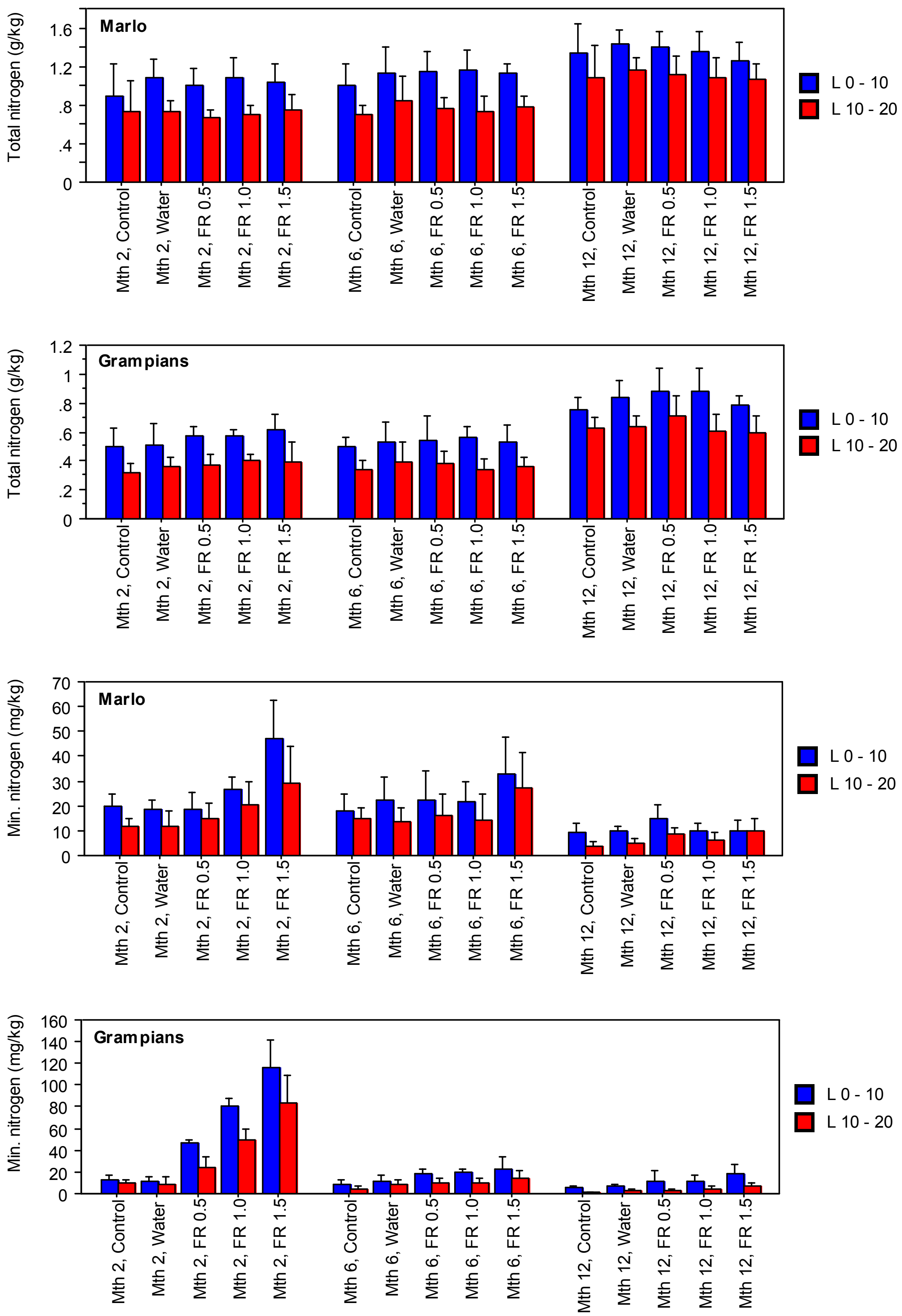

Figure 4 Total and mineralisable nitrogen in soils treated with fire retardant at Marlo and the Grampians Bars indicate standard deviations.

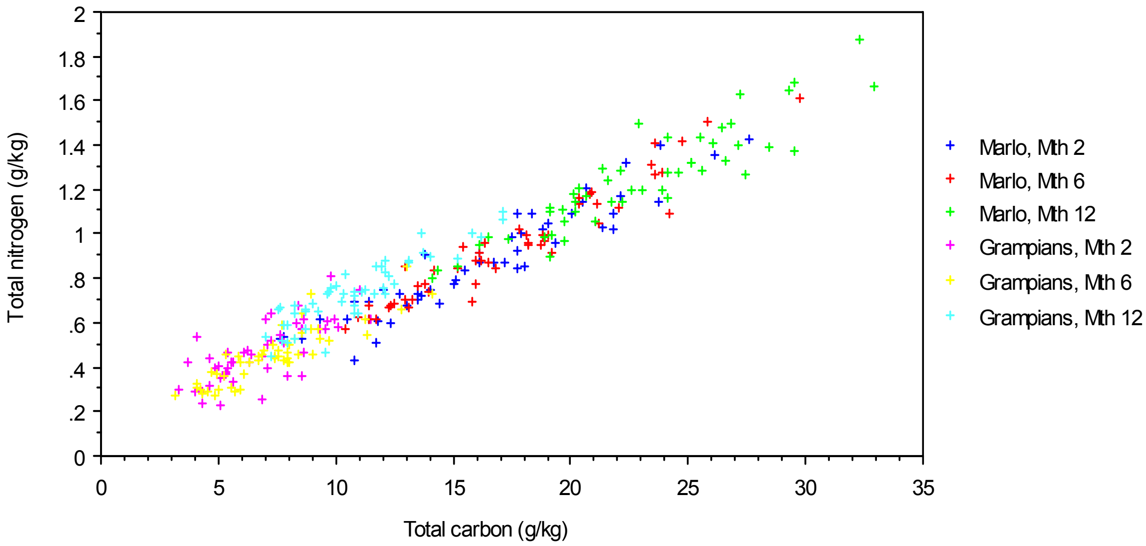

Figure 5 Ratios of total carbon and nitrogen in soils collected 2, 6 and 12 months after applications of fire retardant at Marlo and the Grampians

Extractable phosphorus

Treatment with retardant containing mono- and di-ammonium phosphates equivalent to broadcast applications of elemental P at rates of 31, 63 and 94 kg/ha (see Table 1) did have considerable impact on the levels of extractable phosphorus in the surface soils at both sites (Figure 6). The extractant used (acidified ammonium fluoride) readily dissolves most inorganic forms of phosphorus in soil (Rayment & Higginson 1992) thus providing an estimate of the change in mineral P in the soil due to the application of fire retardant.

At Marlo, levels of extractable P changed gradually with time, increasing from 1.0 mg/kg in the surface soil to 3.6, 7.1 and 9.4 mg/kg at 2, 6 and 12 months respectively after application of retardant at the highest rate (Figure 6). This site showed a significant build up of P in the soil with time, with extractable P levels increasing approximately four-fold compared with the control plots. The changes in soil P followed a different trend at the Grampians site where P levels increased dramatically after 2 months from 0.6 mg/kg in control plots to 2.5, 13 and 36 mg/kg for retardant applied at 0.5, 1.0 and 1.5 L/m^2 respectively. Levels of P then declined rapidly with time but still remained significantly above background levels after 12 months (Figure 6).

Two months after application of fire retardant at rates of 0.5, 1.0 and 1.5 L/m^2, the change in content of extractable P in the soil to a depth of 20 cm was estimated at only 0.6, 3.5 and 5.0 kg/ha respectively at Marlo. Levels of P content in soil increased at this site and after 12 months was estimated at 3.9, 9.7 and 12.7 kg/ha or 13%, 15% and 14% respectively of the amounts applied. In contrast, P levels were highest after 2 months at the Grampians site. Content of the soil to 20 cm were estimated at 2.2, 17 and 48 kg/ha, representing 7%, 27% and 51% of the amounts of P applied in fire retardant. The content decreased with time at this site and, after 12 months, the amounts of P in the soil represented between 12% and 15% of P applied.

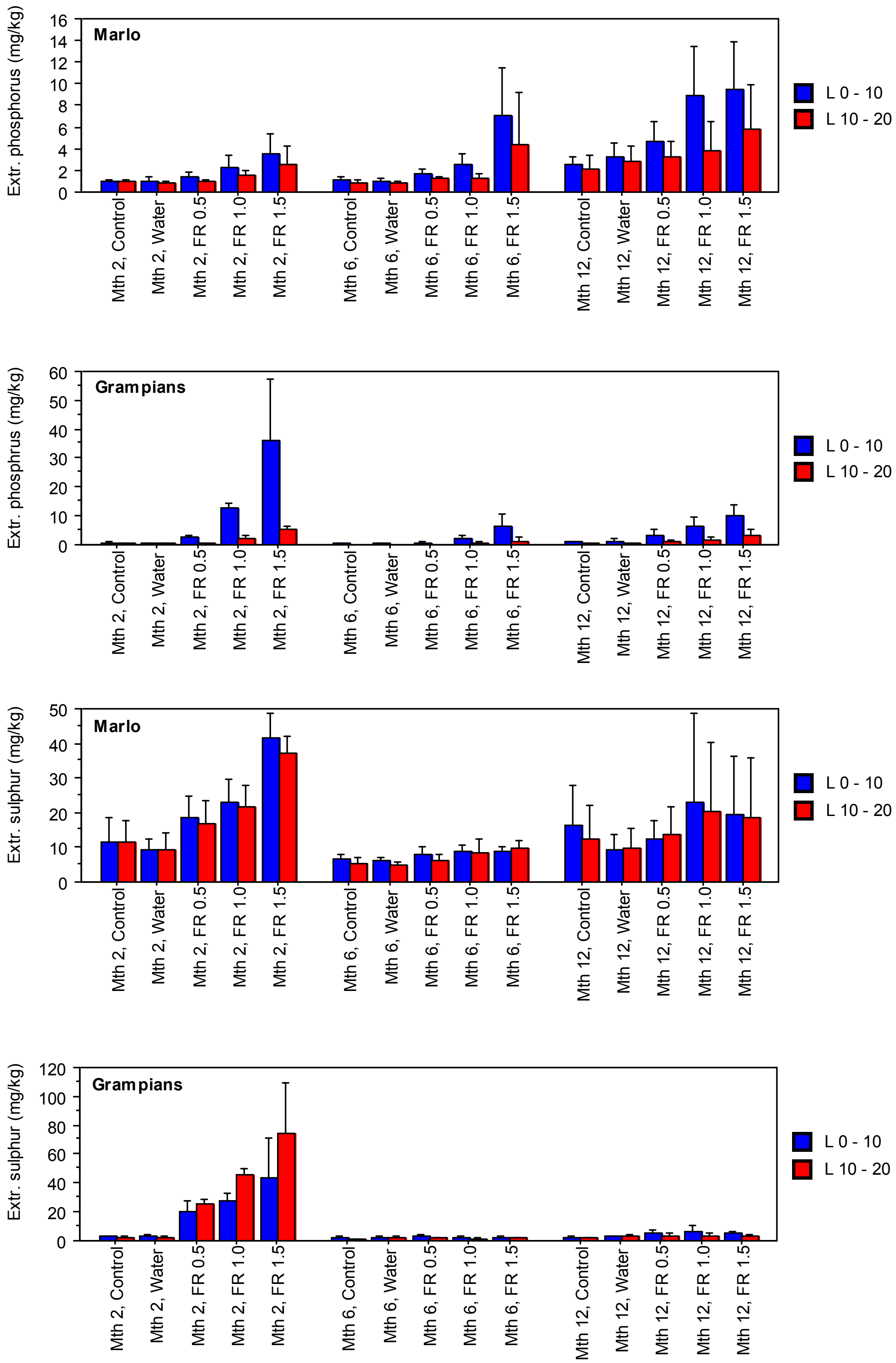

Figure 6 Extractable phosphorus and sulphur in soils treated with fire retardant at Marlo and the Grampians

Bars indicate standard deviations.

Extractable Sulphur

Applications of retardant containing ammonium sulphate at rates equivalent to elemental S at 109, 219 and 328 kg/ha (see Table 1) increased the levels of extractable S in the surface soils considerably at both sites (Figure 6). At Marlo, average concentrations of S in the 0–10 cm and 10–20 cm layers were similar and increased from 12 mg/kg in control plots to 17, 23 and 39 mg/kg 2 months after application of retardant at rates of 0.5, 1.0 and 1.5 L/m^2 respectively. At the Grampians the same treatments raised average levels of S in soil from 3 mg/kg to 23, 37 and 59 mg/kg. Concentrations of S declined gradually at the Marlo site where differences between treatments were still evident after 6 and 12 months (Figure 6). In contrast, a rapid decline in extractable S to levels similar to those in the control plots was observed at the Grampians site.

Two months after the application of retardant at 0.5, 1.0 and 1.5 L/m^2, the change in S content of soil (0–20 cm) was estimated at 14, 26 and 67 kg/ha or 13%, 12% respectively and 20% of the amounts of S applied at the Marlo site. At the Grampians, the same treatments increased the S content in soil to 48, 83 and 136 kg/ha or 44%, 38% and 41% of the amounts applied.

Discussion

This investigation examined the effects of Phos-Chek unmodified by the heat of fire on soil properties for up to 12 months after application of the retardant. Rates of application of Phos-Chek (0.5, 1.0 and 1.5 L/m^2) were selected to reflect current operational use. The experimental areas were not burned and therefore the results of this study reflect the full impact of retardant chemicals on soil properties. At these rates, the amounts of nitrogen, sulphur and phosphorus applied are similar to those used in fertilisers in plantation forestry to correct nutrient deficiencies and stimulate tree growth (Bennett et al. 1996; Fife & Nambiar 1999; Hopmans et al. 1995; Turner & Lambert 1986). Likewise, applications of nitrogen and phosphorus at similar rates increased the growth of trees and understorey vegetation in native eucalypt forests (Grove 1988; Stoneman et al. 1997). However, the composition of understorey species in Karri forest (*Eucalyptus diversicolor*) changed in favour of leguminous species in response to P fertiliser (Grove 1988). A recent study of the effects of thinning and fertilisation of Silvertop Ash (*E. sieberi*) forest on understorey vegetation showed that species diversity and richness were not affected significantly but the abundance of herbaceous species and ground ferns increased (Bauhus et al. 1999).

The present study was conducted in Victoria at heathland sites near the Marlo coast in East Gippsland and the upper reaches of the Glenelg River in the Victoria Valley of the Grampians. This was based on the assumption that the 'fertiliser' impact of fire retardant is likely to be greatest in ecosystems such as heathland communities adapted to a low nutrient environment (Handreck 1997; Heddle & Specht 1975).

Application of retardant containing mainly ammonium sulphates and phosphates and guar gum (used as a thickening agent) is expected to affect soil pH and salinity as well as nitrogen, sulphur and phosphorus in soil profiles. Therefore, the soil tests selected included pH, EC, total carbon and N as well as mineralisable N and extractable P and S. The specific impact of other minor components in Phos-Chek such as iron oxide (colouring agent) and performance additives were not investigated in this study. It should be noted that the observed changes in soil properties were due to retardant unaffected by the heating and oxidation as would occur with a fire. Heating of retardant at the high temperatures associated with wildfire causes significant volatile losses of ammonium and converts the sulphates and phosphates into their corresponding acids that may also be volatilised (CSIRO 2000). The impact of residues of retardant remaining after fire was not considered in this study.

Observed response in soil acidification to applications of Phos-Chek was a decrease in soil pH by up to 0.5 units (from 5.2 to 4.8) at Marlo and up to 0.3 units (from 5.2 to 4.9) in surface soil at the Grampians site. The effect of retardant on soil pH was still evident after 12 months and further soil monitoring would be required to determine the long-term impact in the soil profile. The observed change in pH resulting from a single application of retardant is comparatively small but, nevertheless, decreased pH just below the range of natural variation at both sites. It is therefore important to establish the longevity of the impact of retardant on soil pH.

The effect of retardant on soil salinity was comparatively minor at Marlo where the background level of soluble salts in the surface soil was high and variable across the site (EC: 115 ± 140 µS/cm). As a consequence, the applications of retardant did not significantly change soil salinity beyond the range of natural variation at this site. In contrast, retardant increased soil salinity markedly from a low background (EC: 20 ± 8 µS/cm) to 150 µS/cm after 2 months for the highest rate of Phos-Chek application at the Grampians site. However, changes in salinity of the surface soil were of short duration and there was little difference between treatments after 6 months, indicating rapid leaching of salts deeper into the soil profile. Both sites showed higher levels of salinity in the surface soils across all treatments at 12 months when the sites were waterlogged. This increase in salinity of the surface soil is attributed to a rise of soluble salts from deeper in the soil profile. Under these conditions the residual effect of retardant applications were still evident at the Grampians where background salinity was low.

At the Grampians, salinity was strongly correlated with the level of extractable sulphate in the surface soil, providing further evidence for the direct contribution of retardant to soil salinity at this site. A similar trend was observed at Marlo but here the relationship was weaker because of the high and variable background level of soil salinity at this site.

The application of Phos-Chek containing guar gum was estimated to contribute up to 0.03 g/kg of carbon to the surface soil (0–20 cm). This addition of carbon sources was very small compared with the average levels of total carbon in surface soils at Marlo (21 ± 5 g/kg) and the Grampians (9 ± 2 g/kg). While the amount of carbon applied seems insignificant in terms of total soil carbon, the guar gum adds readily-available sources of carbohydrates to the soil and therefore may stimulate microbial activity for a short period. This will be less of a concern under operational fire management conditions when it is expected that most of the guar gum will be oxidised and volatilised by fire (CSIRO 2000).

Operational applications of Phos-Chek contribute large amounts of ammonium to the surface soil; in this case approximately 340 kg N/ha was applied at the highest rate of retardant. This represents a potential increase in the surface soil of 0.14 g/kg with average levels of total N of 1.08 ± 0.33 g/kg at Marlo and 0.58 ± 0.15 g/kg at the Grampians site. Monitoring of total soil N for one year showed that the impact of retardant on total soil N was relatively minor and generally within the range of natural variation of total N in the surface soil at both sites. In contrast, the highest rate of retardant raised the levels of readily available or labile forms of N about three-fold at Marlo and nearly ten-fold at the Grampians. However, this dramatic increase in labile N was of short duration and levels declined rapidly to background values after 12 months. The change in labile N after 2 months at Marlo was much smaller than expected, indicating that significant amounts of retardant N had already been leached below the maximum sampling depth of 20 cm. In contrast, levels of labile N after 2 months were very high and represented between 53% and 64% of the amounts applied at the Grampians site, indicating a longer residence time of N in the surface soil at this site.

The observed responses in labile N are consistent with the changes in N mineralisation in podzolised sands following applications of ammonium sulphate at 200 kg N/ha in a Radiata pine plantation (Carlyle 1995). This study showed that approximately 74% of fertiliser N was leached below 30 cm in the soil profile within 2 years. However, growth responses continued for 6 years. Likewise, the present study showed a dramatic increase in labile N and presumably uptake of N by heathland vegetation. Although growth of new shoots was enhanced for several species, there was no significant change in height growth after one year (Bell 2003). However, results from other studies indicate that the uptake of N and growth responses can be expected to continue for several years after treatment (Carlyle 1995; Grove 1988; Heddle & Specht 1975).

Applications of ammonium phosphate in Phos-Chek progressively increased extractable P in the surface soil from 2 to 9 mg/kg at Marlo after 12 months. This represented approximately 14% of the total amount of P applied at the highest application rate. In contrast, a rapid increase in extractable P from 2 to 36 mg/kg was observed after 2 months at the Grampians site and this was followed by a decline to 10 mg/kg after 12 months. This represented around 50% of the amount applied at the highest rate after 2 months decreasing to 15% after 12 months. The long-term change in extractable P was similar for both sites indicating a significant increase in labile P in the surface soil after 12 months. The results also indicate that a large proportion of the phosphate applied in retardant has been leached into the subsoil (below 20 cm) where it would still be available at least to the deeper-rooting trees and shrubs. It is important to determine the changes in available P in the soil profile at least to the maximum depth of the root zone, as the accumulation of P in this zone would represent a significant change in soil fertility. It is suggested that this could have a significant impact on the long-term growth and species composition of heathland at both sites. For example, a study of the impact of a single application of sodium nitrate (750 kg/ha) and superphosphate (1400 kg/ha) applied to heathland on Dark Island, South Australia increased growth, shortened life cycles and changed the species composition in favour of herbaceous species over a period of 20 years (Heddle & Specht 1975).

The amounts of sulphate applied in retardant were substantial (range 109 to 328 kg S/ha) and levels of extractable S in the surface soil increased dramatically at both sites. Soil responses differed significantly between the two sites with a three-fold increase in labile S after 2 months reducing rapidly to background levels thereafter at Marlo. In contrast, labile S increased nearly twenty-fold after 2 months at the Grampians site but also declined rapid to background levels. The impact of these changes in soil sulphate on native vegetation is largely unknown. Unlike phosphate, adsorption of sulphate on clay particles is weak and therefore sulphate is likely to have leached rapidly into the subsoil where it contributes to soluble salts stored in the soil profile. It can only be assumed that, under these conditions, the impact of retardant on the uptake of S by heathland vegetation is of short duration, although deeper-rooting species may well periodically access sulphate in shallow groundwater at these sites.

Conclusions

Applications of Phos-Chek at rates representative of the operational use of this retardant for the control of wildfire caused significant short-term changes in the properties of surface soils of heathlands at Marlo and the Grampians. Monitoring of properties of surface soils to a depth of 20 cm was conducted at 2, 6 and 12 months after treatment and provided an insight into the short-term impact of the application of retardant containing ammonium sulphates and phosphates, guar gum and small amounts of iron oxide and performance additives. The application of retardant at rates required for effective control of fire (1.5 L/m^2 of a solution of 14% Phos-Chek) equate to broadcast applications of elemental N, P and S of approximately 340, 90 and 330 kg/ha respectively. Plant nutrients applied at these rates can be expected to have a significant impact on nutrient uptake and growth of vegetation—in particular heathland ecosystems adapted to a low nutrient environment. Fertilisers containing these nutrients are often used at similar rates to correct nutrient deficiencies and stimulate growth of softwood and hardwood plantations.

The impact of Phos-Chek on surface soils at Marlo and the Grampians can be summarised as:

- Retardant decreased soil pH by up to 0.5 units to pH 4.8 at Marlo and by 0.3 units to pH 4.9 at the Grampians site. The effect on soil pH was still evident after 12 months and further soil monitoring would be required to determine the long-term impact in the soil profile.
- Short-term increases in soil salinity at both sites were followed by a rapid decline to pre-treatment values within 12 months. Salinity was strongly correlated with extractable sulphate in the soil at the Grampians, indicating that the sulphate in the retardant was the main cause of the increase in salinity measured at this site. The effect of retardant on salinity was more complex at Marlo because of the relatively high background of soil salinity here.
- The impact of retardant on total carbon and N in soil was relatively minor and within the range of natural variation of C and N in the surface soil at both sites.
- At the highest rate of retardant application, levels of readily-available or labile forms of N increased about three-fold at Marlo and nearly ten-fold at the Grampians. This substantial increase in available N was of short duration and levels declined rapidly to background values after 12 months.
- Applications of Phos-Chek progressively increased extractable P in the surface soil from 2 to 9 mg/kg at Marlo. In contrast, a rapid increase in extractable P from 2 to 36 mg/kg was observed after 2 months at the Grampians site followed by a decline to 10 mg/kg after 12 months. The long-term change in extractable P was similar for both sites indicating a significant increase in labile P in the surface soil after 12 months. Results also indicate that a large proportion of the phosphate applied in the retardant has been leached into the subsoil.
- Retardant applied at the highest rate caused a three-fold increase in labile sulphate after 2 months at Marlo followed by a rapid decline to background levels. In contrast, labile S increased nearly twenty-fold after 2 months at the Grampians site but was also followed by a rapid decline to background levels. Results indicate that sulphate applied has leached rapidly into the subsoil where it contributes to soluble salts stored in the soil profile.

Recommendations

This study showed some important changes in soil properties in the short term including salinity, pH and labile forms of nitrogen, phosphorus and sulphate. There is also evidence of more long-term changes in extractable phosphate and, to a lesser extent, soil pH. Monitoring of soil properties was limited to the surface soil (0–20 cm) but results indicate significant leaching of retardant into the subsoil. In particular, it is important to determine the accumulation of phosphate in the soil profile at least to the maximum depth of the root zone. It is expected that this could have a long-term impact on the growth and composition of heathland vegetation at these sites. It is therefore recommended that these experimental sites be maintained to allow further monitoring of soil profiles and vegetation in 2005, four years after application of the retardant. This should provide a better insight into the longer-term impact of retardant on soils and on the growth and composition of heathland vegetation.

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