Combustion losses of sulphur from conifer foliage: Implications of chemical form and soil nitrogen status

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Abstract. The proportion of total sulphur lost during combustion (600 °C) of Douglas-fir (*Pseudotsuga menziesii*) foliage is reduced from > 90% to 65—70% as the SO_4-S concentration increases from < 10% to 45—50% of the total S content. Foliar SO_4-S content is decreased by improvement of plant nitrogen status, suggesting that alterations to soil N availability may influence S transfer to the atmosphere during biomass burning.

Introduction

Recent interest in global environmental change has drawn attention to the role of biomass burning in exchanges between terrestrial ecosystems and the atmosphere (Mooney et al. 1987). Globally, this source has been estimated to contribute 7 Tg of sulphur to the atmosphere annually, assuming a volatilization efficiency of 50% and a 0.2% S concentration in the 6800 Tg of biomass burned (Andreae 1985). In the Pacific Northwest, the main form of anthropogenic biomass burning is the use of prescribed fire for disposing of logging residues. In Oregon and Washington, approximately 80,000 ha of forest land are treated with prescribed fire annually (Walstad & Seidel 1990), while for British Columbia, 50,000 ha is a reasonable estimate (M. Feller, Faculty of Forestry, U.B.C. pers. comm.).

Field measurements of S losses from biomass burning have found that relative to N, percentage S losses may be higher (Ewel et al. 1981), lower (Delmas 1982), or identical (Raison 1980). These variations have not been addressed in the literature, and little attention has been given to the susceptibilities of various biomass S forms to loss during combustion.

In plants, most inorganic S taken up is converted to organic forms, with proteins accounting for about 80% of the organic S (Rennenberg 1984). In plants with an abundant S supply and/or nitrogen deficiency, excess S

accumulates as inorganic sulphate, as shown for Douglas-fir (*Pseudotsuga menziesii*) by Turner et al. (1977, 1980).

At temperatures typical of biomass fires, amino acid S and inorganic SO_4-S behave quite differently. For example, sulphur amino acids oxidize at temperatures (200–450 °C) at which inorganic sulphate salts are stable (Liptry 1974). Although Vlamis & Gowans (1961) and Attiwill & Leeper (1987) noted that these differences may affect S losses during biomass burning, direct experimental evidence was not provided. Therefore, the hypothesis to be tested is that an increasing proportion of total S present in sulphate form should reduce the degree of S loss during combustion of plant materials.

Methods

For this experiment we used the foliage of Douglas-fir, a major commercial tree species in the Pacific Northwest. As part of a forest fertilization study, Carter & Klinka (1988) analyzed current-year foliage from 104 20–50 year-old Douglas-fir stands occurring across a range of environments in coastal British Columbia. We selected 16 of these samples, representing a wide range in foliar SO_4-S concentrations (Table 1). Foliar total S determinations in that study were made with a Fisher Model 475 S Analyzer (Guthrie & Lower 1984) and SO_4-S was extracted in boiling 0.01 N HCl(1 g foliage in 20 mL for 10 min) and determined by HI-reduction (Johnson & Nishita 1952).

Two-g samples of dried, ground foliage were placed in uncovered ceramic crucibles and ignited in a muffle furnace at 400 °C (30 min), 600 °C (30min), and 800 °C (1 h). These temperatures represent the lower and middle part of the range observed in prescribed fires (Tiedemann 1987). After removal from the furnace, the crucibles were cooled in a desiccator, weighed, and total S concentrations determined on the ash as above. Percentage S losses were calculated from the initial and ignited sample weights and S concentrations.

Results and discussion

The mean percent S loss at 600 °C (78.5%) was significantly different from the loss at 400 °C (69.8%), but not from that at 800 °C (79.3%) (one-way ANOVA, Tukey's HSD, 5% significance level). A similar trend to a reduced rate of increase in S loss with increasing temperature was reported by Tiedemann (1987). These results provide further evidence

Table 1. Sulphur concentrations in current-year foliage (dry matter basis) of selected Douglas-fir stands (Carter & Klinka 1988).

Stand No.	Total Sulphur (%)	Sulphate-S	
		mg/kg	% of total S
1	0.137	214	15.6
5	0.136	360	26.5
6	0.164	589	35.9
7	0.154	447	29.0
8	0.145	317	21.9
12	0.137	237	17.3
13	0.118	152	12.9
15	0.140	371	26.5
19	0.132	176	13.3
21	0.164	550	33.5
22	0.157	480	30.6
102	0.095	75	7.9
106	0.170	815	47.9
107	0.152	575	37.8
114	0.145	715	49.3
136	0.080	55	6.9

that short duration, low temperature combustion can cause substantial losses of S from forest residues.

At all three temperatures, highly significant negative linear relationships existed between the percentage of total S lost and the SO_4-S content of the foliage, expressed either as concentration (mg/kg) or as a percentage of the total S content (Fig. 1, 2).

These results support the initial hypothesis that an increasing SO_4-S content reduces the potential S loss during combustion of foliage. This has several implications for S losses during biomass burning, particularly in relation to soil N availability.

— Potential S losses from prescribed fire should tend to be smaller when N, but not S, is limiting stand growth and excess S has accumulated as sulphate in the foliage.

— Fertilization with N only, as is often practiced in forestry, results in conversion of excess foliar SO_4-S to organic forms (Turner et al. 1980). The latter appear to be much more volatile, so the potential S loss in a subsequent prescribed fire would be increased.

— The relevance of these findings to prescribed fires after forest harvesting may be complicated by transformations and losses of S from
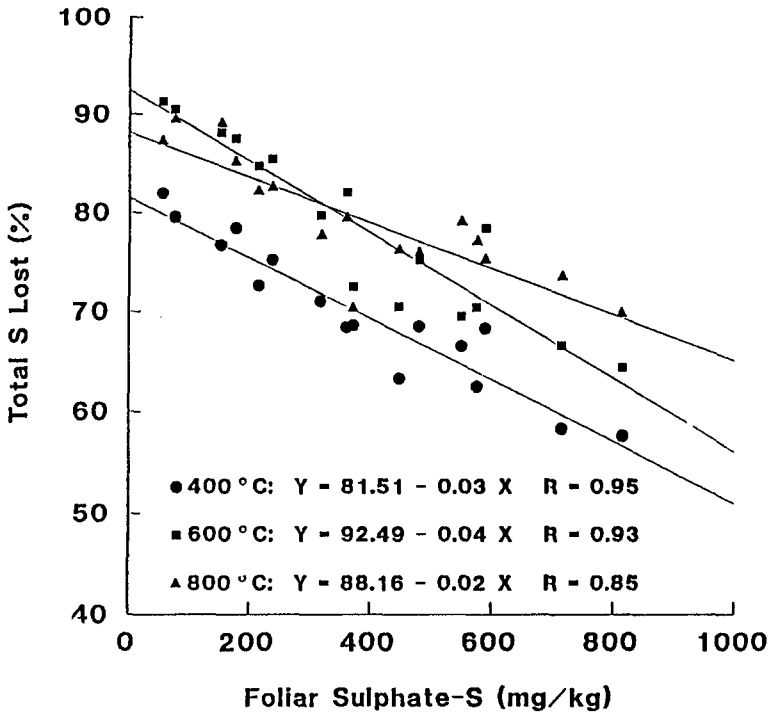
Fig. 1. Relationships between percentage of total sulphur lost during combustion of Douglas-fir foliage (at three temperatures) and concentration of foliar sulphate-S in dry matter.

logging residues prior to burning. For example, more than 50% of the S content of green *Pinus radiata* needles may be lost by leaching and decomposition after 12 months in the field (Baker et al. 1989). Therefore, if a year or more elapses between logging and prescribed fire, much of the foliage will have fallen to the forest floor and experienced substantial losses of S, with SO_4-S likely being particularly susceptible to leaching.

— The lower susceptibility of SO_4-S to combustion loss, if applicable to organic sulphates in forest floors, may explain observations by Tiedemann (1987) that S in Douglas-fir foliage is less resistant to combustion than in forest floor materials. At sites in central Vancouver Island, British Columbia, the proportion of total S occurring as ester sulphates increases from the least (Oi) to most (Oa) humified horizons in forest floors (Sanborn & Ballard, manuscript in preparation). Such a trend may also be accompanied by a reduction in susceptibility to combustion S loss.
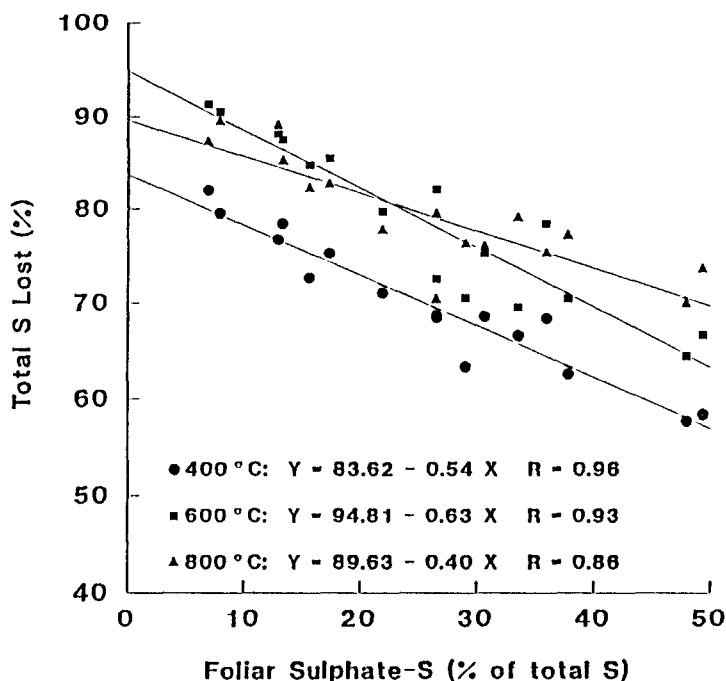
Fig. 2. Relationships between percentage of total sulphur lost during combustion of Douglas-fir foliage (at three temperatures) and proportion of total S in dry matter consisting of sulphate-S.

Summary and conclusions

Substantial losses of S can occur in low temperature combustion (400, 600 °C). Increasing concentrations and proportions of foliar SO_4-S significantly reduce the percentage of total S lost during biomass combustion. Through interactions with soil N availability which control the proportion of foliar S occurring as sulphate, this effect may influence potential S losses in subsequent fires. The significance of these findings for operational prescribed fire may depend on losses and transformations of S in forest residues prior to burning. If organic sulphates in forest floors are also less susceptible to combustion loss than other forms of organic S, the vulnerability of forest floor S may be controlled by the degree of humification.

Acknowledgements

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