ELEMENTAL SULPHUR DUST DEPOSITION ON SOILS AND VEGETATION OF LODGEPOLE PINE STANDS IN WEST-CENTRAL ALBERTA

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Abstract: The influence of the addition of elemental sulphur dust on forest vegetation and soils in west-central Alberta was studied using four sites from a larger study on biomonitoring of sulphur effects. The two sites close to the sulphur dust sources (<200 m) had significantly higher total and water soluble soil sulphur contents in all horizons to a depth of 20 cm. Associated soil changes included both the lowering of pH and a reduction in the total concentration of Mg, K and Mn in the LFH horizon. The effect of the S deposition on the vegetation was the almost complete elimination of the mosses and a reduction in the herb cover. Research is continuing on the controlling factors in the oxidation of elemental S in the soil, the effects of the S dust on soil processes such as nutrient leaching, and the response of vegetation to the changes in soil chemistry.

The natural gas processing industry is the largest anthropogenic sulphur source in western Canada. Almost half of the natural gas found in Alberta (the major gas and oil producing province in Canada) is sour; that is, it contains significant quantities (up to 30 per cent) of H_2S. There are 109 sour gas processing plants scattered throughout the province and collectively they processed 6.5×10^{10} m^3 of gas in 1981 (Energy Resources Conservation Board, Report 82-D, 1982). The gas industry as a whole is very efficient in sulphur recovery (97 per cent) as compared with other sulphur releasing industries in western Canada such as oil sands mining and processing (65 to 85 per cent) or nonferrous smelting (80 per cent).

High efficiencies in the extraction of S from natural gas results in large amounts of the element S being produced. Before 1979, most of the recovered S was poured into blocks which accumulated millions of tonnes. An improvement in the S market initiated break-up or melting of accumulated blocks. The methods used for handling S resulted in the production of elemental S dust and although largely confined to the immediate vicinity of the plants (i.e., <1 km), contributed significant quantities to local soils.

In 1981, we initiated a study in consultation with Canterra Energy Company Ltd. (formerly Aquitaine Company of Canada) and Gulf Canada to assess the impact of S emissions from two sour gas processing plants on the forest system.

The specific objective of this paper is to describe preliminary results as to the magnitude of the impact of the deposition of elemental S particulates on forest soils and vegetation.

Study Area

The study area (Figure 1) is located approximately 45 km southwest of Rocky Mountain House, Alberta. The lower elevation forest type is dominated by *Pinus contorta* var.

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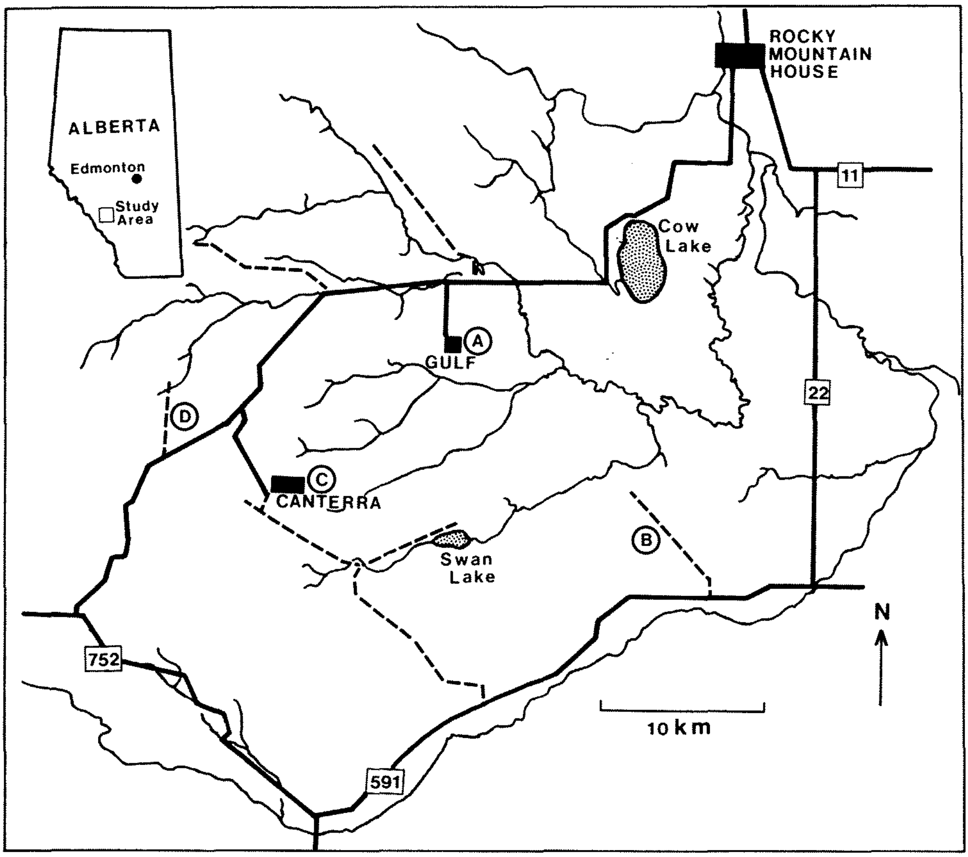

Figure 1. Location of the Gulf and Canterra gas plants and study sites (A, B, C, D) within the study area.

latifolia and the soils are mainly Brunisolic or Podzolic Gray Luvisols with subdominants of Orthic Gray Luvisols and Eluviated Dystric Brunisols. These soils have developed on a glacial till parent material that has a 20 to 30 cm aeolian veneer.

Sites A and C are located respectively 50 and 200 m from the Gulf and Canterra sulphur blocks (Figure 1) and sites B and D represent controls which are at least 9 km from the source. The sites were selected so that the vegetation was as similar as possible. All sites are characterized by 25 m *Pinus contorta* with *Vaccinium vitis-idaea* var. *minus*, *V. myrtilloides*, *Cornus canadensis*, *Pleurozium schreberi*, and *Hylocomium splendens*. Variation in vegetation does occur however, and appears to be related to elevation and stand age. It was on this basis that control sites (B and D) were selected to match the two sites that are in close proximity to the sulphur blocks. The stands at sites A and B are young (49 and 53 years) and are at low elevations (1200 and 1160 m). They are of a mixed wood composition with *Populus tremuloides* and *Picea glauca* in the tree layer, *Alnus crispa* and *Ledum groenlandicum* in the shrub stratum and the herbs *Pyrola asarifolia*, *Viola renifolia* and *Arnica cordifolia*.

The stands at sites C and D are older (75 years) and at higher elevations (1400 and

1420 m) than sites A and B. The species at site D include *Abies balsamea, Rubus pedatus, Antennaria neglecta, Pyrola secunda,* and *Arnica cordifolia.*

Materials and Methods

At each site, a 20 × 20 m plot was established within which each tree greater than 1 m in height was recorded as to its species, location, vitality and diameter. Ten *Pinus contorta* (>10 cm DBH) were selected and age was determined on increment cores that passed through the trees' centre. Lower stratum vegetation description of each site was carried out by estimating the cover of each plant species in each of 20 randomly selected and permanently marked quadrants (1 × 1 m).

Ten *Pinus contorta* trees on the perimeter of each plot were selected and felled. Height and diameter (at 30 cm height) were recorded as well as the leader length interval for each of the past five years. The needles and stems of each of the past five years from each of the five youngest lateral branches in excess of five years old were collected. Needles were counted and stem length was measured. Dry weight of both stems and needles were recorded.

Five soil pits were dug at each site and both the description and classification were carried out according to the system of soil classification for Canada (Canada Soil Survey Committee 1978). Samples from each of the four horizons in the top 30 cm of each soil pit were collected. Moist subsamples were extracted with water or ammonium acetate (pH 4.8), at 1:25 moist soil to solution ratio. The pH of the horizons was determined on a saturated soil paste (Richards 1954) also using moist subsamples. The remaining portion of the samples was air-dried and ground to pass through a 100 mesh sieve and digested with $HNO_3 - HClO_3 - HF - HCl$ (modified from McQuaker *et al.* 1979). All solutions were analysed for Ca, Mg, K, Al, Fe, Mn, S and P by inductively coupled argon plasma atomic emission spectrometry (ICAP-AES).

Results and Discussion

The parent material of the four sites consists of a slightly calcareous glacial till overlain by a 20 cm aeolian veneer. The soils of sites A, B and D were classified as Brunisolic Gray Luvisols generally well to moderately well drained. Site C is imperfectly drained with gleying at 6-21 cm and was classified as a gleyed Podzolic Gray Luvisol. The surface texture of the surface mineral horizons ranged from silt loam to clay loam. All four sites had a 3 to 6 cm organic litter layer overlying the mineral soil.

The total soil sulphur data (Table 1) indicated that a large amount of elemental S had been deposited to soils in close proximity to the blocks (sites A and C). The total soil S values were much higher (56,950 and 36,710 $\mu g\ S\ g^{-1}$ soil; sites A and C, respectively) compared with the respective control soils (841 and 1231 $\mu g\ S\ g^{-1}$ soil; sites B and D). The water soluble soil S concentration of all four horizons at site A and C were also considerably higher than those at sites B and D (Table 1). The majority of total S in all horizons at the control sites appeared to be either organic or adsorbed since the water soluble S was negligible. At sites A and C, however 20 to 35 per cent of the total S in the LFH horizon and greater than 60 per cent in the mineral horizon (total S of the Ae_2 horizon of site A was only 40 per cent water soluble S) was water soluble.

Table 1. Total soil sulphur, water soluble sulphur concentrations and pH of the four surface horizons at selected sites at varying distances from sulphur dust sources

Site		pH[a]	Soil sulphur[b] (μg.g^{-1}) Total	Water soluble
A	(.05 km)			
	LFH	2.5(2.4-2.7)	56950 ± 10210	10550 ± 6370
	Ael	4.1(3.7-4.9)	225 ± 56	186 ± 83
	Bf	5.3(4.9-5.4)	258 ± 53	154 ± 74
	Ae2	5.1(4.9-5.5)	104 ± 33	37 ± 32
B	(9 km)			
	LFH	5.2(4.4-5.5)	841 ± 220	29 ± 4
	Ae	4.9(4.0-5.4)	90 ± 12	3 ± 2
	Bf	5.5(5.0-6.0)	100 ± 13	4 ± 6
	2Ae	5.2(5.1-5.5)	67 ± 12	1 ± 1
C	(0.2 km)			
	LFH	3.0(1.6-5.4)	36710 ± 9780	13110 ± 10160
	Ahe	4.1(3.8-4.5)	349 ± 100	479 ± 206
	2ABgj	4.5(4.4-4.6)	280 ± 103	300 ± 154
	2Bfgj	4.5(4.4-4.7)	207 ± 72	197 ± 125
D	(18 km)			
	LFH	4.5(4.3-4.7)	1231 ± 142	31 ± 17
	Ahe	4.7(4.5-5.1)	107 ± 39	0
	Bf	5.4(5.2-5.7)	113 ± 19	2 ± 3
	2Bm	5.5(5.2-6.0)	102 ± 42	0

[a] Values are average pH and the range.
[b] Values are means ± 95 per cent confidence limits.

Decreases of approximately two pH units in the LFH horizons of sites A and C were observed (Table 1). Smaller decreases in the pH (approximately 0.5 pH unit) of the Ae horizon of both sites A and C and the two lower horizons of site C were also observed. Increases in the water soluble S content and a decrease in the pH of the LFH horizon indicate the oxidation of elemental S, probably by microbial activity.

Total soil analysis for the various horizons at the four sites are given in Table 2. The total Ca concentrations were considerably higher in the LFH of sites A and C compared with B and D. The high levels of Ca (sites A and C) are the result of lime ($CaCO_3$) applications of approximately 2.5 tonnes ha^{-1} applied by aircraft in 1979 and 1980. The high concentrations of Ca in the LFH horizon along with the high concentrations of S suggest that $CaSO_4$ (gypsum) could be an important constituent of the LFH horizon at sites A and C. Total Mg, K, Mn, Fe and Al concentrations in the LFH horizons of sites A and C are lower than at their respective control sites. Studies in the literature suggest the addition of sulphate in the form of acid rain can have a potential effect on leaching (Cole and Johnson 1977; Mollitor and Raynal 1982) and ion translocation processes (Johnson and Cole 1980; Hovland *et al.* 1980). In addition, the high concentrations of Ca in the LFH could be important in the leaching of other cations from the LFH horizon. Excessive Ca in the LFH, as a result of liming, could result in the replacement of other cations on the exchange sites by Ca, subjecting them to leaching. No conclusive evidence is available however, and decreases in the nutrient content of the LFH horizon also may be a result of

Table 2. Total soil calcium, magnesium, potassium, manganese, iron and aluminum of the four surface horizons at selected sites at varying distances from sulphur dust sources. Values are means ± 95 per cent confidence limits.

	Total soil concentrations ($\mu g.g^{-1}$)					
Site	Ca	Mg	K	Mn	Fe	Al
A (0.05 km)						
LFH	11488 ± 6227	722 ± 434	1856 ± 639	649 ± 996	3532 ± 2321	7985 ± 4580
Ael	3276 ± 493	1801 ± 38	8615 ± 609	282 ± 183	7131 ± 1301	29867 ± 1881
Bf	2772 ± 429	2160 ± 202	7494 ± 442	183 ± 47	11934 ± 1568	36227 ± 4105
Ae2	1954 ± 95	2398 ± 227	8632 ± 209	80 ± 11	9440 ± 965	27019 ± 1742
B (9.0 km)						
LFH	6525 ± 2466	1759 ± 404	3003 ± 622	3145 ± 4733	5370 ± 2490	11831 ± 3842
Ae	2717 ± 245	1467 ± 198	8222 ± 561	264 ± 269	5929 ± 1003	24440 ± 1992
Bf	2242 ± 468	1738 ± 59	7180 ± 300	179 ± 58	9659 ± 882	28222 ± 7267
2Ae	2108 ± 333	2592 ± 1084	8187 ± 1116	127 ± 28	10108 ± 1032	26128 ± 5982
C (0.2 km)						
LFH	18714 ± 24557	577 ± 229	1035 ± 370	143 ± 81	2913 ± 1602	5711 ± 2979
Ahe	3058 ± 730	2168 ± 248	8172 ± 554	254 ± 230	8702 ± 1441	31904 ± 2752
2ABgj	1952 ± 899	2344 ± 391	7175 ± 344	209 ± 124	11404 ± 2002	32104 ± 6021
2Bfgj	1539 ± 151	2823 ± 305	7698 ± 272	130 ± 22	13953 ± 2852	30040 ± 2078
D (18 km)						
LFH	4192 ± 989	931 ± 215	1963 ± 95	706 ± 378	3669 ± 2946	6180 ± 2973
Ahe	1794 ± 377	1622 ± 567	6605 ± 598	172 ± 103	9278 ± 3056	25821 ± 5072
Bf	2085 ± 1766	1722 ± 182	6791 ± 1905	173 ± 92	11464 ± 6006	27127 ± 6502
2Bm	920 ± 270	2053 ± 117	6454 ± 394	119 ± 36	14721 ± 1965	25443 ± 3135

Table 3. Species number and cover in selected *Pinus contorta* stands in the vicinity of sulphur dust sources

Site	Stand Age (years)	Distance from source (km)	Number of species			Per cent cover		
			Shrubs	Herbs	Mosses	Shrubs	Herbs	Mosses
A	49	.05	7	11	4	5	10	1
B	53	9.0	8	8	6	6	7	16
C	76	0.2	7	10	1	7	4	0
D	75	18.0	3	11	7	3	7	18

Table 4. Growth of *Pinus contorta* at selected sites at varying distances from sulphur dust sources. Values are means ± 95 per cent confidence limits

Site	Tree		Terminal growth $cm \cdot year^{-1}$	Lateral branch	
	Age (years)	Height (m)		Growth $cm \cdot year^{-1}$	Needle production $g \cdot cm^{-1}$
A	49	17.5 ± 1.3	26.5 ± 7.3	7.8 ± 1.0	0.86 ± 0.08
B	53	15.3 ± 2.2	21.7 ± 7.6	5.5 ± 0.8	0.80 ± 0.06
C	76	20.3 ± 1.3	13.3 ± 2.9	5.3 ± 0.6	0.83 ± 0.10
D	75	17.9 ± 3.9	8.3 ± 4.3	3.5 ± 0.5	0.64 ± 0.11

a reduction in litter fall. Thus while the data (Table 2) indicated a decrease in the total concentration of Mg, K, Mn, Fe and Al, in the LFH horizon of the sites in close proximity to the S block the reasons for the decrease are largely unknown and are currently under investigation.

The effect of the elemental S dusting on the vegetation was dramatic particularly on the mosses (Table 3). Both the number of mosses and their cover were reduced as was the cover at site C as compared with site D. Site A showed a similar reduction of cover when compared with site B but there did not appear to be any effect on either the composition or cover of herbaceous species. The difference between the young (A and B) and old (C and D) sites in the response of the herbs appears to be related to a combination of the magnitude of deposition and the duration of exposure.

There did not appear to be any response of woody plants to the soil changes described above (Tables 3 and 4). None of the growth measurements taken on *Pinus contorta* gave any indication of an effect of elemental S addition. In fact, site D appeared to be much less productive with respect to tree growth than any of the other sites studied (Table 4). Also there were fewer species and a smaller cover of shrubs at site D than at site C (Table 3).

In general, even though there has been an almost total elimination of mosses at sites that have had significant elemental S deposition, there is no measurable response of woody species. It appears that before tree and shrub species are affected, soil chemical changes will need to be more intense or of longer duration.

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Literature Cited

Canada Soil Survey Committee. 1978. The Canadian system of soil classification. Res. Branch, Can. Dep. Agric. Publ. 1646. Ottawa, Ontario.

Cole, D.W. and D.W. Johnson. 1977. Atmospheric sulfate additions and cation leaching in a Douglas Fir ecosystem. Water Resource Res. 13: 313-317.

Energy Resources Conservation Board. 1982. Sour gas processing in Alberta. A review of evidence presented at the recent ERCB hearings respecting the impacts and surveillance of sour gas plants. ERCB Report 82-D. Energy Resources Conservation Board, Calgary, Alberta.

Hovland, J., G. Abrahamsen and G. Ogner. 1980. Effects of artificial acid rain on decomposition of spruce needles and on mobilisation and leaching of elements. Plant and Soil, 56: 365-378.

Johnson, D.W. and D.W. Cole. 1980. Anion mobility in soils: Relevance to nutrient transport from forest ecosystems. Environ. International 3: 79-90.

McQuaker, N.R., D.F. Brown and P.D. Kluckner. 1979. Digestion of environmental materials for analysis by inductively coupled plasma-atomic emission spectrometry. Analytical Chem. 51: 1082-1084.

Mollitor, A.V. and D.J. Raynal. 1982. Acid precipitation and ionic movements in Adirondack forest soils. J. Soil Sci. Soc. Am. 46: 137-141.

Richards, L.A. (Ed.). 1954. Diagnosis and improvement of saline and alkali soils. U.S. Salinity Laboratory, U.S.D.A., Handbook 60.