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INJURY TO VEGETATION CAUSED BY INDUSTRIAL EMISSIONS OF BORON COMPOUNDS

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In the immediate surroundings of a fiberglass industry in central Sweden, vegetation shows toxicity symptoms. Soils and birch leaves were sampled. The soil was analysed for water soluble and organic bound boron, carbon, nitrogen, and pH. Vegetation was analysed for total boron. Both fractions of boron in the soils increase towards the factory. Organic bound boron increases irregularly because of its strong correlation to carbon content which varies in the area. The C/N ratio increases nearer the industry due to the harmful effect of boron on decomposition of organic matter. No relation between pH and the distance from the emission source is visible, but the B/C ratio was found to increase with increasing pH of the soil. Boron levels in birch leaves are elevated very much close to the factory. The geographical distribution of high levels of boron in birch, corresponds well with high values in soils, and also with the main wind directions. The limit values for visible injury on birch are found to be around 5 ppm of water soluble boron in soil and around 200 ppm in leaves.

INTRODUCTION

The boron found in soil is normally generated by weathering of the wide spread mineral, turmaline. Near the coast there is an addition from deposition of sea salts, and enhanced levels can be found around boron emitting industries. Boron occurs as an anion in the soil, weakly adsorbed to soil colloides and is therefore readily leached out. Deficiency of the element is common especially on acid soils in humid areas (BERGER, 1949; MORTVEDT et al., 1972).

Boron appears in three main fractions in the soil: mineral bound, fixed to mineral and organic colloides, and readily soluble. Several factors influence the fixation such as pH, the content of clay, of organic matter and of iron and aluminium hydroxides (HATCHER et al., 1967). The active groups seem to be the OH-part in iron and aluminium hydroxides, and the diols in organic molecules (HINGSTONS, 1964, SIMS & BINGHAM, 1968, MORTVEDT et al., 1972). The fixation increases with rising pH levels especially at pH higher than 6–7, with increasing content of clay and of organic matter. The organic matter is the main source of easily soluble boron in soil (GUPTA, 1968).

In relation to most plants, boron is a micronutrient and the step from necessary to toxic levels is very small. It is one of those trace elements which most often cause deficiency symptoms in agricultural crops (RUSSEL, 1971). When in excess, the boron concentration in the plant, is in proportion to the levels in the growing medium (KATALYMOW, 1969).

Deficiency of boron first shows in the growing parts of the plant. The mechanisms of this and other functions are not yet made clear, but several investigations suggest that boron participates in various ways in the metabolism (BERGER, 1949, KATALYMOW, 1969).

The purpose of this study was to assess the concentration of boron in soil and vegetation around a boron emitting fiberglass industry and to find the cause of the vegetation injury found in the close neighbourhood of that industry.

The factory is situated by the seaside at a bay of the Baltic sea, 20 km northeast of Sundsvall city. The area can be divided into two parts. One part follows the coast and is a steep slope that consists of no longer cultivated pasture, homes and gardens, and small plots with deciduous trees, mostly birch. Above the slope at an altitude of about 40 m, the coniferous area takes over. The slope soils are mainly silty to sandy in character, with high content of organic matter in the top layer. The main wind direction is along the sealine, especially in summer, when land and sea breezes are dominating.

MATERIALS AND METHODS

Samples of birch leaves (*Betula verrucosa*) and of soil down to 10 cm depth, were taken at 17 sites, distributed along three lines from the industry. Three soil profiles divided into 5 cm intervals, down to around 30 cm depth were also taken.

The soil samples were analysed for the following factors: pH in 0.01 M $CaCl_2$, total content of carbon and nitrogen, and the content of water soluble and organic bound boron. The boron found after ashing was considered to be organic bound. The vegetation samples were dry ashed. All boron samples were analysed with the diantrimide method (BERGER & TROUGH, 1939).

RESULT AND DISCUSSION

Soil

The pH values of the 17 samples vary between 4.9 and 7.1 with an average of 5.9. No pronounced relation is found between soil pH and distance from the industry, Table 1. The distribution of the sampling sites is found in Figure 1. The emission of 525 tons of sulfur dioxide per year does not seem to acidify the soil. The pH in the profiles is almost constant with depth, Table 2.

The carbon content in the 17 samples varies from 5.2 to 14.8 % with an average of 8.0 %. The carbon levels are relatively high. One part of the explanation can be that the samples are taken on no longer cultivated pastures with a high litter production. The enhanced content of boron can also be involved. By blocking the OH-groups boron can impede the decomposition of the organic matter leading to an elevated carbon-nitrogen ratio. As can be seen in Table 1 there is a tendency of increasing C/N ratio towards the industry.

The content of the two fractions of boron is listed in Tables 1 and 2. The concentrations are increasing toward the industry more regularly for water soluble than for organic bound boron. The increase is more evident in the two directions along the sealine than along the line into the inland. There is an almost tenfold increase of both fractions close to the factory in comparison to the reference site. The concentrations are still higher than normal in the soil samples at the outermost ends of the three lines. The reference site unfortunately was shown to be influenced by the factory, but other investigations show background values of about 0.5 mg/kg soil (KATALYMOW, 1969). Sample site 8 has boron values which are on the same level as those of the outhermost sites, but although it is situated only 200 m from the emission source it is out of the main wind direction.

Figure 1 gives the distribution of water soluble boron in soil. The isolines representing 2.1 and 4.7 ppm divide the boron values into three classes. 30 % are lower than 2.1, 30 % higher than 4.7 and 40 % between 2.1 and 4.7 ppm. The obtained

Table 1. pH in 0.01 M $CaCl_2$, carbon content, the carbon nitrogen ratio and content of water soluble and organic bound boron in 17 soil samples. Content of boron in leaves of birch (*Betula verrucosa*) at the same sample sites.

				Boron mg/kg			Boron mg/kg
Sample site	pH $CaCl_2$	% C	C/N	Water soluble	Organic bound	B/C	Birch leaves
1	4.9	11.1	35	12.1	10.2	0.91	913
2	7.1	6.4	27	9.9	19.2	3.00	–
3	6.7	5.2	19	7.9	5.6	1.07	450
4	5.7	9.5	16	7.5	4.9	0.52	207
5	6.1	9.1	17	4.7	7.2	0.78	138
6	5.9	8.0	15	2.9	3.6	0.45	82
7	6.5	8.8	14	2.1	6.0	0.68	68
8	6.1	4.8	14	2.7	2.8	0.59	50
9	5.9	8.7	14	4.4	7.7	0.89	123
10	6.1	14.5	19	3.6	9.4	0.65	138
11	5.7	5.7	12	2.2	3.0	0.53	129
12	5.6	5.2	12	2.2	1.2	0.23	47
13	5.7	4.1	16	2.3	2.2	0.53	195
14	6.0	6.4	13	2.0	3.3	0.52	71
15	5.5	7.6	13	0.7	2.2	0.29	84
16	5.8	14.8	15	1.8	2.8	0.19	48
17(ref.)	4.9	5.6	13	1.0	1.0	0.18	53

figure corresponds well with the main wind directions. A narrow about 700 m wide and 7 km long stripe along the sealine shows elevated concentrations of boron. Almost the same figure is found for organic bound boron.

The distribution of the two boron fractions down the soil profiles is shown in Figure 2. The concentration of organic bound boron in particular is clearly related to the carbon content in the soil. Practically no boron is found in the silt or sand below the humus layer. This confirms the anticipation that boron obtained after ashing is the organic bound fraction. The B/C ratio is plotted against pH in Figure 3. The data represent all samples with carbon content higher than 1 %. The two sampling sites nearest the industry, 1 and 2, are marked with rings and the four outermost ones, 12, 15, 16 and 17, with crosses. The figure shows that the fixation of boron to organic matter is strongly pH dependent. The irregularity of organic boron increases towards the industry, Table 1, thus is explained both by the variation in pH and the variation of carbon content in the soil in this area. An equilibrium exists between all forms of boron in the soil (BERGER, 1949). A reservoir of organic bound boron will be built up when the deposition of boron exceeds the uptake by vegetation and leachage. This reservoir will be a source of boron available to vegetation long after the emission of boron has ceased.

Vegetation

A detailed assessment of the air pollution injury to vegetation in the area is made regularly within an environmental protection control programme. In the assessment for the period of interest for this study symptoms of air pollution injury were clear in the area close to the factory, Figure 1 (KVIST, 1979, KVIST & JAKOBSSON, 1980). On deciduous

Table 2. pH in 0.01 M $CaCl_2$, carbon content, the carbon nitrogen ratio and content of water soluble and organic bound boron in three soil profiles.

					Boron mg/kg		
Sample site	Depth cm	pH $CaCl_2$	% C	C/N	Water soluble	Organic bound	B/C
3	0–5	7.1	7.7	15	10.9	13.1	1.70
	5–10	7.4	7.4	20	7.6	12.2	1.65
	10–15	7.3	7.3	18	6.7	13.7	1.87
	15–20	7.1	6.7	17	6.0	9.6	1.44
	20–25	6.8	4.0	16	4.0	3.5	0.87
5	0–5	6.0	11.1	17	3.2	9.0	0.81
	5–10	6.0	9.4	17	3.5	7.5	0.80
	10–15	6.0	9.0	18	3.6	7.1	0.79
	15–20	6.1	3.0	16	2.1	2.5	0.83
	20–25	6.3	0.3	8	0.8	2.6	8.13
9	0–5	5.8	10.5	14	4.8	8.9	0.85
	5–10	5.8	8.5	14	3.3	6.9	0.81
	10–15	6.0	8.3	14	3.8	6.1	0.74
	15–20	6.0	8.3	14	3.0	6.4	0.77
	20–25	6.0	2.4	13	1.3	2.3	0.96
	25–30	6.2	0.3	7	0.3	0.7	2.41
	30–35	6.7	0.1	6	< 0.2	0.9	7.50

trees the leaves show symptoms varying from slight chlorosis via marginal and intercostal chlorosis, marginal and intercostal necrosis to entire dead leaves and also totally killed trees. Also herbs are injured occasionally. Coniferous trees are affected, showing chlorotic needles, too early shedding of needles and in some cases at exposed sites also tip necrosis of needles. The symptoms were seen in the same area all through the growing season but increasing in intensity with time.

Other authors describe the symptoms of boron toxicity, caused by excessive soil levels, on deciduous trees and herbs mainly as marginal chlorosis or necrosis. Leaves of grass species react with tipchlorosis or necrosis (OERTLI & KOHL, 1961, TEMPLE et al., 1978). Injury has been reported from the surroundings of fiberglass industries in connection with fluoride emissions (TEMPLE et al., 1978). It should be noted that no elevated levels of fluorine has been found in soil or in vegetation in this study.

Birch was chosen for the vegetation sampling because of its rich abundance and the strong visible injury that appears on the species close to the industry. The result of the boron analyses is shown in Table 1. The levels are enhanced in the whole area. The highest values are found close to the factory and in the area directly to the SSE. This is in accordance with what would be expected considering the main wind directions and the content of available boron in the soil. A compilation of vegetation injury and boron content of leaves and soils, Figure 1, shows a good correlation between the factors. EATON & WILCOX (1939) state that boron levels in soil exceeding 0.5–5 ppm, depending on plant sensitivity, are phytotoxic, and SMIDT & WHITTON (1975) give 200 ppm in plant leaves as a toxic limit value. In an avenue of birches, which was heavily injured with dead branches and extensive leaf necrosis, the average of boron concentrations in the leaves is 550 ppm. Further away from the factory the levels drop fast down to 50 ppm in the most remote sites. A reference sample taken from another part of the country has a boron concentration of

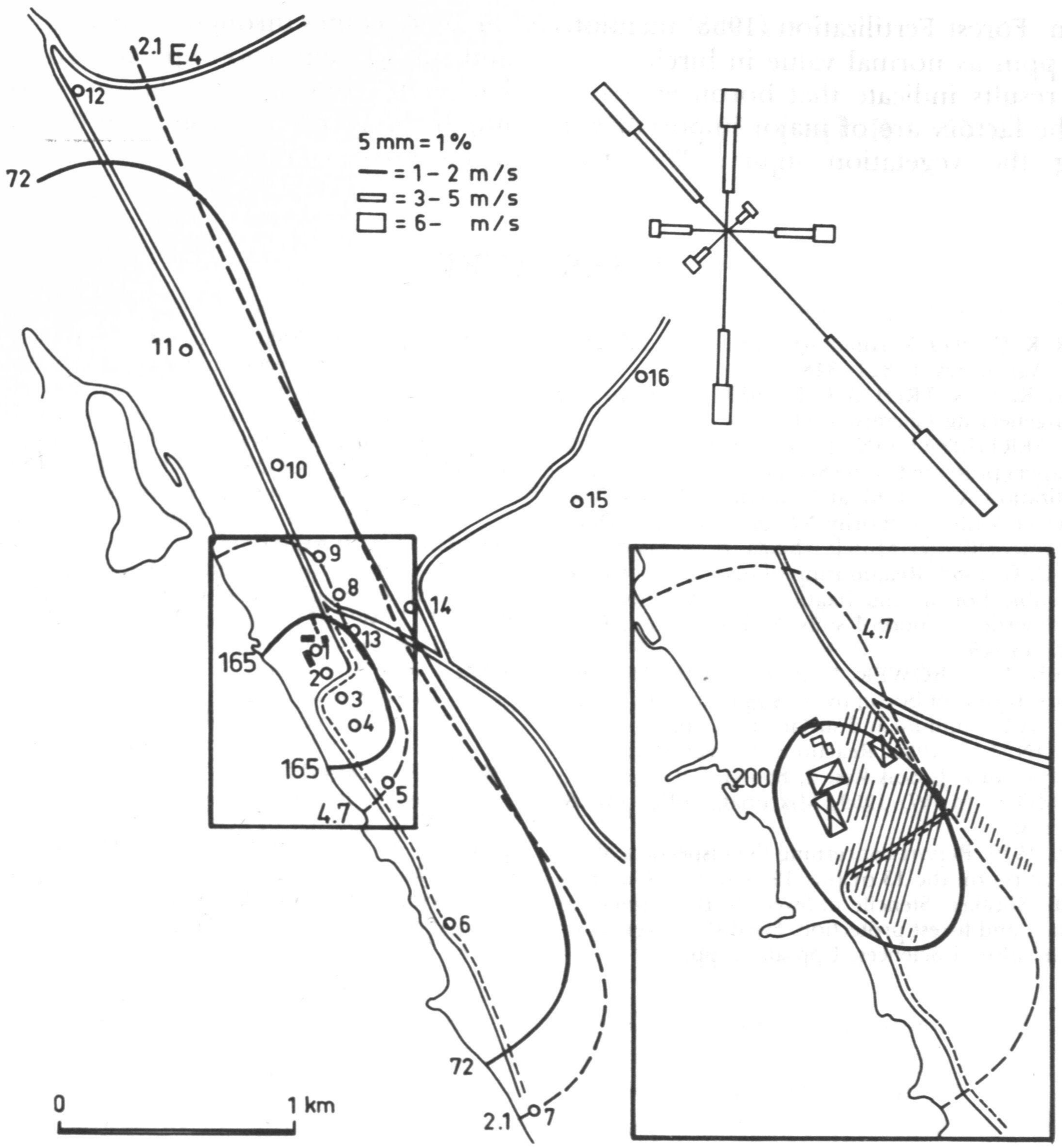

Figure 1. The geographical distribution of the content of water soluble boron in the 10 cm top-soil (-) and the content of boron in vegetation (—). The shadowed area in the enlarged square indicates the area with visible injury on vegetation.

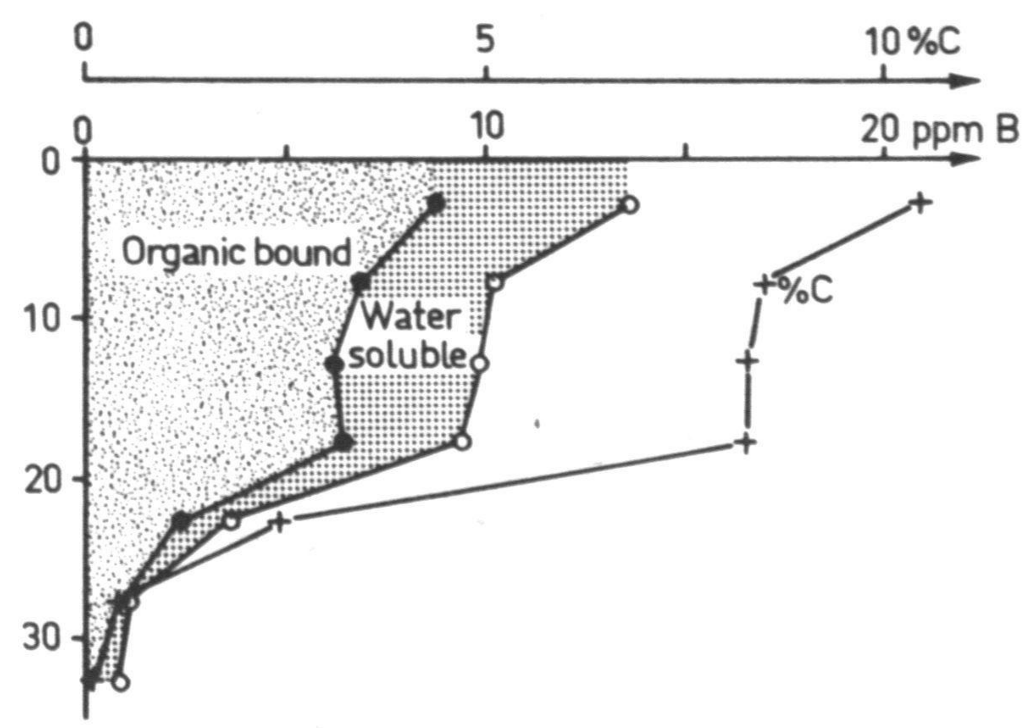

Figure 2. The distribution of organic bound and water soluble boron and carbon in the soil profile at site 9.

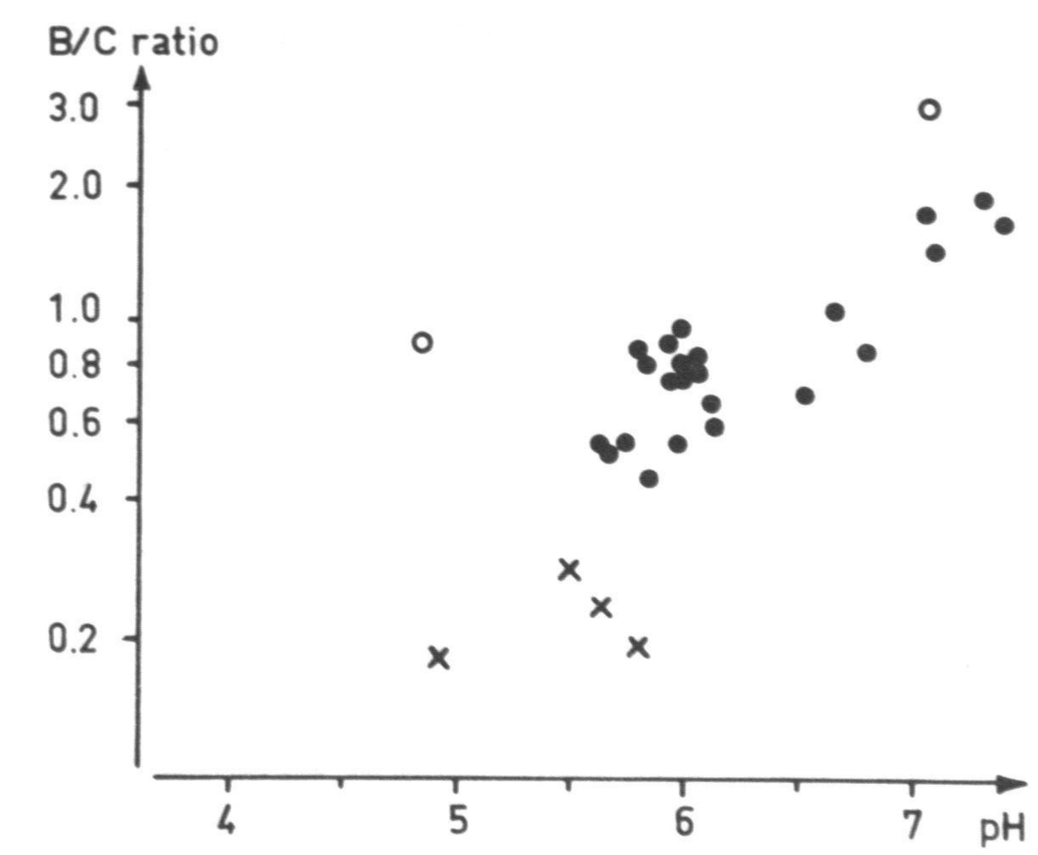

Figure 3. The relationship between the boron-carbon ratio and pH in soil.

24 ppm. Forest Fertilization (1968) mentions 29–32 ppm as normal value in birch.

The results indicate that boron emissions from the factory are of major importance in causing the vegetation injury. The main influence comes through accumulation in soil and subsequent root uptake. Too little is known for drawing conclusions about how important a contribution from direct uptake in the leaves can be.

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