Effects of Atmospheric Deposition of Sodium Sulfate on Bean and Tomato Plants

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INTRODUCTION

Severe injury to vegetation has occasionally been observed in the vicinity of pulp and paper mills in Ontario. Although vegetation injury was usually associated with accidental releases of sulfur dioxide (SO_2) from sulfite mills (LINZON, et al, 1972) vegetation has also been injured in the vicinity of kraft mills, where ambient SO_2 concentrations were low and foliar injury symptoms did not resemble those caused by SO_2 (GRIFFIN 1976). Sodium sulfate (Na_2SO_4) has been identified as a major air pollutant emitted by kraft pulp and paper mills (ADAMS and KOPPE, 1966; HASTINGS et al, 1972). Sodium concentrations in vegetation samples collected in the severe foliar injury zone around a kraft mill in northwestern Ontario averaged 10-50 times normal levels (GRIFFIN 1976), so sodium sulfate was implicated as a potential phytotoxic pollutant. Dustfall levels in the vicinity of this mill averaged between 11 and 14 g/m^2/30 days and ranged as high as 28 g/m^2/30 days. Most of the dustfall would appear to be sodium sulfate (H. GRIFFIN, pers. communication) indicating a rate of deposition of nearly one gram of sodium sulfate per square meter per day within 200 to 300 meters of the pulp mill, with higher rates of deposition closer to the mill. The levels of sodium sulfate applied to plants in this experiment reflected the high concentrations of this material encountered in the vicinity of the pulp mill. The objective of these experimental exposures was to determine the effects of atmospheric deposition of sodium sulfate on plants, and to compare injury symptoms on treated plants with those observed in the field.

METHODS

The plants used for the experiments were Pinto beans and "Veemore" tomatoes, representative of species commonly grown in home gardens around pulp and paper mills. Pinto beans were 28 days old and tomato plants were 35 days old at the beginning of the experiment. Plants were grown in a greenhouse equipped with an activated charcoal air filtration system under conditions of 22°C day and 18°C night temperature, 50-55% relative humidity and 12 hour photoperiod.

Technical grade sodium sulfate was ground with a mortar and pestle to a fine powder. This was dusted onto the leaves of bean and tomato plants which had been moistened with a fine spray of distilled water to simulate dew formation. The saltcake was applied up to three times each week at rates of 0, 0.5, 1.0, 3.0 and 5.0 grams per treatment. Six replicate plants were used for each treatment. Measurements of plant heights and leaf lengths were taken weekly. At the end of the experiment, four weeks for Pinto bean and three weeks for tomato, injury symptoms were noted and dry weights of individual plant parts were measured. The plants and soil were subsequently analyzed for sodium contents by conventional atomic absorption spectrophotometry.

Bulletin of Environmental Contamination & Toxicology,
0007-4861/78/0019-0257 $1.40

RESULTS

A. Plant Growth

Pinto beans

Plant heights of Pinto beans after exposure to sodium sulfate are given in Table 1. After one week of exposure, the 0.5 g treatment had no effect on plant growth, but plants exposed to 1.0 g were significantly smaller than control plants ($p > 0.01$). The higher rates of application, 3 and 5 g also significantly reduced plant growth. No visible injury was observed on plants treated at rates of 0.5 and 1 g per application. Plants exposed to 3 g per treatment had 30% of leaves with light marginal necrosis. Injury on plants treated with 5 g per application increased from 30% of leaves with light ($< 15\%$) marginal necrosis to an additional 50% of leaves with severe ($> 35\%$) marginal necrosis and wilt.

Table 1

Effect of sodium sulfate on plant growth of Pinto beans; mean of six replicates per treatment

Rate of treatment (g/application)	Total salt load (g)	Plant height (cm)
1 Week:		
0	0	23.2^{a}
0.5	2	22.7^{a}
1	4	21.5^{b}
3	12	18.8^{c}
5	20	19.8^{c}
2 Weeks:		
0	0	25.7^{a}
0.5	3.5	23.8^{a}
1	7	22.8^{b}
3	21	18.8^{c}
5	25	19.0^{c}
3 Weeks:		
0	0	27.3^{a}
0.5	5	26.3^{b}
1	10	21.3^{c}
3	-	necrotic
5	-	necrotic
4 Weeks:		
0	0	27.9^{a}
0.5	6.5	24.8^{b}
1	13	21.7^{c}

Differences between means with different superscripts are highly significant ($p < 0.01$)

After two weeks of treatment the 0.5 g rate of application had no effect on plant growth, but the 1 g rate significantly reduced plant height and leaf lengths. The higher rates of application reduced plant growth to an even greater degree, but the difference between the 3 g and 5 g treatments was not significant. Plants treated with 5 g per application had become totally necrotic after two weeks and this rate of application was discontinued. At the 3 g rate, one replicate showed severe necrosis and wilt, two were moderate, and three were light to moderate. Chlorosis of primary leaves was more severe than on control plants, and flower production was inhibited. No visible injury symptoms were observed at the lower treatment rates.

After three weeks of treatment, inhibition of plant growth by the 0.5 g rate of application had become significant, but no foliar injury symptoms were detected on these plants. Plants exposed to 3 g per treatment had become almost 100% necrotic and this rate of application was discontinued. Browning at the tips of mature leaves was noted, suggesting that the sodium sulfate had become soluble in the soil and had translocated to the leaf tips. No foliar injury was detected at the 1 g rate of treatment.

After four weeks both the 0.5 and 1 g treatments had significantly reduced plant growth. In addition, the average number of bean pods per plant and dry weight of the pods were also reduced by the sodium sulfate treatments. At the 0.5 and 1 g rates of application, plants developed a brown terminal necrosis on 50% of mature leaves, suggesting that toxic amounts of sodium and/or sulfate had translocated to the tips of the leaves.

Veemore tomato

Plant heights of tomato plants treated with saltcake are given in Table 2. Treatment with 3.0 and 5.0 g of saltcake significantly reduced plant growth after one week. After two weeks, the 1.0 g treatment had significantly reduced plant growth, but even after three weeks of treatment the 0.5 g rate of application had no significant effect on plant growth. No visible injury was observed on any of the tomato plants after the first week of treatment. During the second week, plants given the 5.0 g rate showed severe desiccation and foliar necrosis. During the third week of treatment, the plants treated at the rate of 3.0 g also developed severe desiccation and necrosis. In both cases, injury developed quickly when the total salt load had reached 30 g. Tomatoes given the lighter salt treatments showed only trace brown tipping on leaves.

TABLE 2

Effects of sodium sulfate on plant growth of "Veemore" tomatoes; mean of six replicates per treatment

Rate of treatment (g/application)	Total salt load (g)	Plant height (cm)
1 Week:		
0	0	20.3[a]
0.5	1.5	20.3[a]
1	3	19.7[a]
3	9	17.3[b]
5	15	17.4[b]
2 Weeks:		
0	0	21.4[a]
0.5	3	21.1[a]
1	6	19.2[b]
3	18	17.1[c]
5	30	17.0[c]
3 Weeks:		
0	0	23.5[a]
0.5	5	23.4[a]
1	10	21.3[b]
3	30	17.1[c]

Differences between means with different superscripts are highly significant ($p < 0.01$)

B. Dry Weight and Chemical Analyses

Bean plants underwent a steady reduction in dry weight of foliage in response to increasing levels of sodium sulfate deposition, while tomato plants showed no effects at low levels and a gradual reduction in dry weight of foliage at higher sodium sulfate loadings (Table 3). The response of root growth to sodium sulfate in both species was similar.

Both beans and tomatoes showed a steady reduction in root mass with increasing amounts of sodium sulfate deposition.

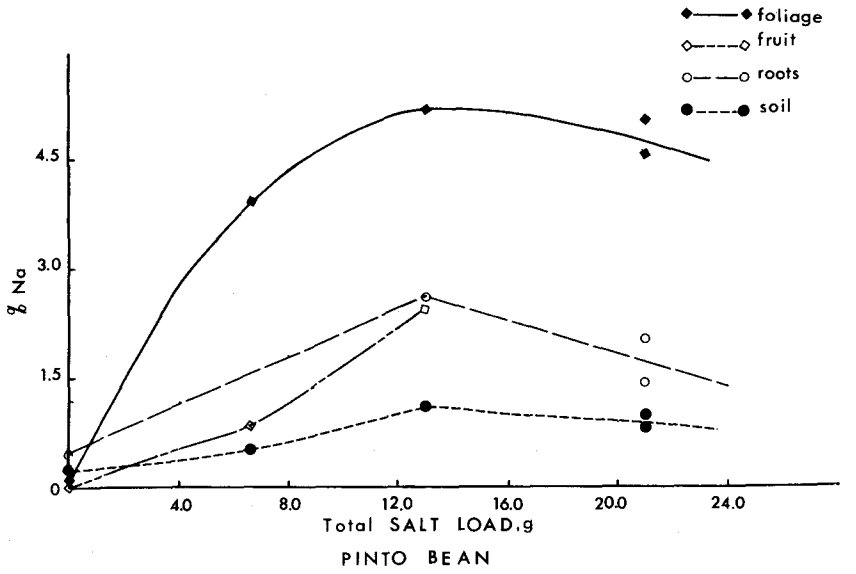

Figure 1 - Accumulation of sodium in Pinto bean plants and soil with increasing levels of sodium sulfate deposition.

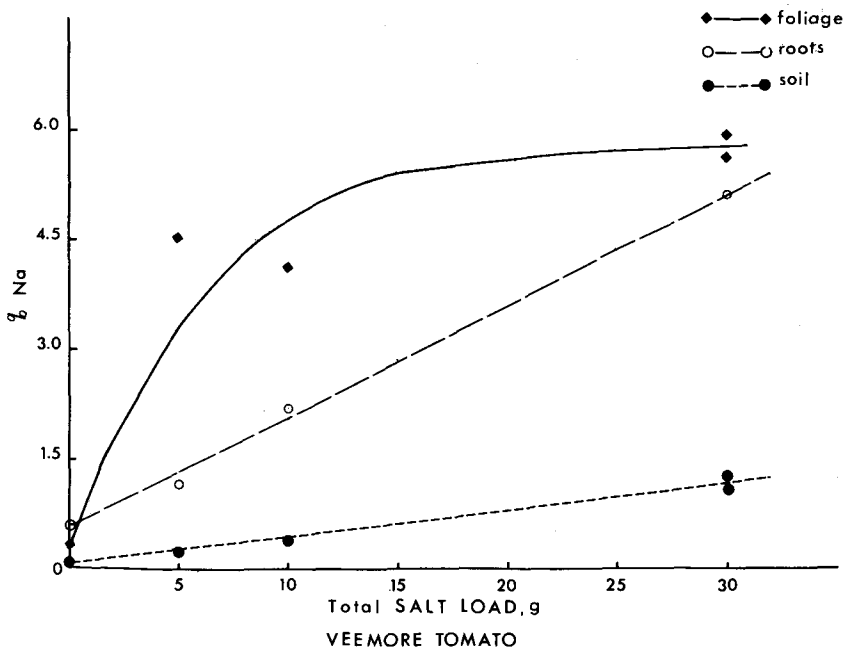

Figure 2 Accumulation of sodium in tomato plants and soil with increasing levels of sodium sulfate deposition.

Table 3

Effects of sodium sulfate on dry weights of tomato and bean plants after three weeks of treatment; mean of six replicates per treatment

Rate of treatment (g/application)	Total salt load, g	Tomato, dry wt. g. leaves	roots	Bean, dry wt. g. leaves	roots	pods
0	0	12.8	2.4	13.6	1.6	4.4
0.5	5	12.5	1.6	6.8	1.3	2.1
1	10	10.6	1.4	4.9	0.8	0.3
3	30	4.4	0.5	3.4	0.5	0
5	30	3.8	0.2	3.6	0.3	0

Foliar levels of sodium increased rapidly in bean plants, while sodium contents of fruit and roots increased gradually (Fig. 1). Above the 12 gram level the sodium content of roots declined, possibly because the plants were desiccated or necrotic and the roots were no longer physiologically active. In tomato plants levels of sodium in foliage increased rapidly to a maximum of 5.5 per cent dry weight, while the sodium content of tomato roots increased linearly (Fig. 2). Sodium levels in tomato foliage and roots were significantly greater ($p < 0.01$) than concentrations in bean foliage and roots.

DISCUSSION

Pinto beans and tomatoes differed in their response to sodium sulfate. Beans responded to increasing dosages of sodium sulfate by a steady reduction in plant growth and dry weight. Tomatoes were not affected by the 0.5 and 1 g rates of application, and at the higher rates tomato plants responded by a gradual reduction in plant height and dry weight.

Injury symptoms induced by foliar application of sodium sulfate to bean and tomato plants were characterized by a light brown marginal necrosis and a pronounced wilt of the leaves. These symptoms were not the same as those observed on vegetation injured in the vicinity of the kraft pulp mill (GRIFFIN, 1976) suggesting that the causal agent of vegetation injury around the kraft mill was not sodium sulfate. In addition, although maximum dustfall deposition in the injury zone around the kraft mill was on the order of 100 tons/sq. mile/30 days or approximately 28 g/m^2/30 days rates of deposition averaged over the growing season were lower than dosages of sodium sulfate found to be toxic to plants in these experiments. This suggests that vegetation injury observed around the kraft mill was caused by a substance or combination of substances more toxic to plants than sodium sulfate. However, in these experiments vegetation injury became more pronounced as sodium sulfate levels increased in soil, and sodium and/or sulfate translocated to the tips and margins of leaves. The results of these experiments suggest that sodium sulfate emissions from kraft pulp mills may be injurious to vegetation if concentrations build up in soil, with subsequent uptake and translocation by plants, rather than by direct foliar injury.

ACKNOWLEDGEMENTS

We wish to thank Bob Chai for statistical analyses of the data, L.I. Benedicto for secretarial assistance, and the Vegetation and Soils Unit, Air Quality Laboratory, Ministry of the Environment, for the chemical analyses. The advice and comments of H.D. Griffin and S.N. Linzon are also greatly appreciated.

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