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EFFECTS OF H_2S ON CROP AND FOREST PLANTS

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ABSTRACT

Continuous fumigation of alfalfa, grapes, lettuce, sugar beets, California buckeye, ponderosa pine, and Douglas fir with 3000 parts per billion (ppb) H_2S caused leaf lesions, defoliation, reduced growth, and death of sensitive species. Three hundred ppb caused lesser but similar effects. Sulfur accumulated in leaves depending upon dosage. Lower levels of H_2S, 30 ppb and sometimes 100 ppb, caused significant stimulation in growth of lettuce, sugar beets, and alfalfa. The stimulation occurred at certain times of year. Addition of 50 parts per million (ppm) of CO_2 to the fumigation atmospheres overcame growth reduction caused by 300 ppb H_2S in lettuce and sugar beets. Two varieties of grapes and one variety each of pears and walnuts were fumigated with the highest ambient levels of H_2S found near The Geysers, treble ambient H_2S and amounts of SO_2 equivalent to the treble levels of H_2S. No deleterious growth or fruiting symptoms were observed which could be ascribed to the treatments.

INTRODUCTION

Hydrogen sulfide is a malodorous gas produced by many industrial and biological processes and is often a major component of geothermal emissions. It is highly toxic to man. Extensive power development at The Geysers, Calif. has caused major complaints because of odor and ranchers fear that crops are being injured. Limited studies (1,2) with high level, short term fumigations have shown injury to some crop and weed species but recent studies at the University of California, Riverside (3,4,5) are the only long term, lower level studies designed to assess injury to crop and forest species from geothermal emissions such as those occurring at The Geysers.

EXPERIMENTAL

A. CONTINUOUS CONSTANT LEVEL FUMIGATIONS.

Procedure

To establish basic acute toxicity of H_2S to a number of crop and forest plants growing in The Geysers area, alfalfa (Medicago sativa L), Thompson seedless grapes (Vitis vinifera), lettuce (Lactuca sativa), sugar beets (Beta vulgaris), California buckeye (Aesculus californica), ponderosa pine (Pinus ponderosa), and Douglas fir (Pseudotsuga menziesii) were exposed to serial concentrations of H_2S.

Continuous, uniform level fumigations were conducted in four greenhouses. Hydrogen sulfide was injected into the carbon-filtered, incoming air stream to provide the required concentrations of fumigant.

Three fumigation procedures were employed. In the first series of experiments during 1975, alfalfa, Thompson seedless grapes, ponderosa pine, and California buckeye were exposed to concentrations of 0, 30, 300, and 3000 parts per billion (ppb) of H_2S. Lower pollution levels (0, 30, 100, and 300 ppb) were used in the second fumigation series during 1976 which involved alfalfa, lettuce, sugar beets, Douglas fir, and a second set of Thompson seedless grapes. The third fumigation attempted to simulate effluent gases from The Geysers which contain considerable levels of CO_2 in addition to the H_2S. This study used 0 (control), 30, 100 and 300 ppb H_2S, 300 ppb H_2S + 50 parts per million (ppm) CO_2 and 300 ppb SO_2. The SO_2 was compared because H_2S is oxidized to SO_2 in the atmosphere.

All species of plants were grown in pots. A soil mix consisting of peat moss, redwood shavings, and silt (1-1-1) was used. Mineral salts were added to provide initial fertilization. The plants were irrigated with one-half strength Hoagland's solution twice weekly. All data, where replicated, were analyzed statistically by an analysis of variance and a multiple-range test.

Results

Effects of Continuous H_2S Fumigation on Alfalfa. During 1975 when fumigation levels were 0, 30, 300, and 3000 ppb H_2S, green alfalfa showed white marginal leaf lesions on mature leaves within 5 days at the highest level of H_2S. To determine yield, the plants were cut at 28-35-day intervals. Growth was reduced during the first growing period at both 300 and 3000 ppb H_2S with Hayden (Table 1). The highest level reduced growth of Eldorado, and a trend was shown at 300 ppb. No effect on growth was caused by 30 ppb. During the subsequent growth period, most of the plants died at 3000 ppb, and growth was reduced in both varieties at 300 ppb. Samples of dried tissue from these two cuttings were

analyzed for total sulfur and showed graduated accumulation corresponding to the levels of H_2S in the different atmospheres.

Table 1. Effects of Continuous H_2S Fumigation on Growth and Sulfur Accumulation in Alfalfa[a]

		Alfalfa variety			
		Eldorado		Hayden	
	H_2S, ppb	Av dry wt/ pot, g	Total S as SO_4, %	Av dry wt/ pot, g	Total S as SO_4, %
Cutting #1	0	52 y	1.03	52 x	0 92
13 Aug 1975	30	51 y	1.23	52 x	1.36
	300	42 y	2 45	32 y	2 44
	3000	16 z	4 85	11 z	5 20
Cutting #2	0	45 y	0 94	46 y	1.00
9 Sept 1975	30	46 y	1.10	43 y	1.29
	300	31 z	3.00	28 z	3.41

[a] Values followed by different letters are different at the 1% level

During 1976, fumigation at 3000 ppb was discontinued, and a treatment at 100 ppb H_2S was added in an attempt to determine more precisely the amount of H_2S which caused reduced growth in this crop. Eight successive cuttings were harvested from May until October. The results showed that 300 ppb H_2S caused significantly reduced yields in all cuttings except August 3 and September 21, while 100 ppb had no statistical effect on yield. The lowest level, 30 ppb, significantly increased yields in the late summer, August 3, August 26, and September 21, of 136, 118, and 132%, respectively, of the alfalfa grown in carbon-filtered air. Thus, continuous fumigation with H_2S at 3000 and 300 ppb caused foliar injury and reduced growth. At 100 ppb neither of these effects occurred, and with 30 ppb a significant growth stimulation during summer was observed.

Effects on Grapes. The immediate effect of the 3000 ppb level on grapes was similar to that seen on alfalfa in 1975. White to yellow lesions, which later turned brown, appeared on leaves. Defoliation began to occur after about 4 weeks at the highest level and within several more days almost all leaves were lost. However, the plants were not killed but continued growth of canes and put out small chlorotic leaves until the exposure was terminated. The 300 ppb level caused lesser but similar, readily observable injury. No foliar effects were seen at the 30 ppb level.

Cane length was reduced at the highest H_2S level as compared to the other treatments, but less dieback occurred at 30 and 300 ppb H_2S, Table 2.

Table 2. Effects of Increasing Levels of H_2S on Cane Length, Dead Length, and Dry Weight of Thompson Seedless Grapes[a] 1975

H_2S, ppb	Total length, cm	Dead length, cm	% Dead	Total dry wt, g	Total sulfur as SO_4 in leaves, %
0	1252.9 y	191.3 z	15 5 z	145.0 x	0 78
30	1160.0 y	212 4 z	18.7 z	143.1 x	1.26
300	1090.1 y	572.1 x	53.3 x	72.5 y	3.33
3000	673.5 z	422.2 y	63.1 y	38.0 z	4.50

[a] Values followed by different letters are different at the 1% level

Total dry weight of cane was reduced to one-half with 300 ppb as compared to the control, but the total length was the same statistically, showing that the H_2S caused a thin spindly growth of canes. With 3000 ppb the cane length was about one-half the control, but weight was one-fourth, showing the same effect. Composite leaf samples were analyzed for total sulfur and showed accumulation in grape leaves similar to those in alfalfa.

Significant increase of fresh leaf weight was induced with 30 and 100 ppb H_2S over the controls with the same numerical trend in dry weight (Table 3) in 1976. Fresh weight of canes

Table 3. Effects of Increasing Levels of H_2S on Leaf and Cane Weights of Grapes[a] 1976

	Leaves		Canes	
H_2S, ppb	Fr wt, g	Dry wt, g	Fr wt, g	Dry wt, g
0	265 6 a	78.6 a	267 2 a	123 8 a
30	375 6 b	97.0 a	251.8 a	115 8 ab
100	298 4 b	80 6 a	219 6 a	86.0 bc
300	260 4 a	57.0 b	152 0 b	62.8 c

[a] Values followed by different letters are different at the 5% level

was reduced significantly by 300 ppb, and dry weight with both 300 and 100 ppb. Thus, H_2S caused severe foliar injury and defoliation but was not lethal. The stimulation in fresh weight of leaves with lower levels of H_2S was similar to the effect observed with fresh weight of alfalfa in summer.

Effects on Ponderosa Pine. Little effect of fumigation was observed for 4-6 weeks, but later at the 3000 ppb H_2S level a progressive tip burn was observed with defoliation after 10 weeks of exposure. No visible effect was caused by 30 ppb.

Effects on California Buckeye. The buckeye proved quite resistant to H_2S. At the 3000 ppb level, a bronzing of the leaves occurred after 4 weeks exposure and some defoliation occurred at the highest level after 8 weeks.

Effects on Sugar Beets. Beets were grown, harvested, and analyzed for fresh and dry weight of leaves, percent total sulfur, fresh weight of roots, and percent sugar. Results with individual beets (Table 4) showed that 30 ppb H_2S stimulated fresh weight of leaves and roots 41 and 51%, respectively, but 300 ppb inhibited these two responses significantly and also reduced sugar content in roots. Leaves had much more sulfur per unit weight than roots.

Statistical analyses for the 1976 crop of sugar beets (Table 4) showed the leaf growth was stimulated significantly by both 30 and 100 ppb H_2S. Root weight was significantly greater in 100 ppb H_2S than in the control atmosphere but was statistically the same in the 30 and 300 ppb H_2S.

Effects on Lettuce. Results with the first lettuce crop (Table 5) showed a large stimulation

Table 4. Yield of Leaves, Roots, and Sugar Content of Sugar Beets Exposed to Increasing Levels of H_2S[a]

Individual beets, leaves

H_2S, ppb	Fresh wt, g	Dry wt, g	% Sulfate
0	149 6 bc	19 8 bc	0.66
30	210 5 a	25.2 b	0.93
100	200.8 ab	23.3 b	1.33
300	127.6 c	15 2 c	1.88

Individual beets, roots

H_2S, ppb	Fresh wt, g	% Sugar	% Sulfate
0	291.3 bc	19 3 a	0.05
30	440 6 a	18.3 a	0.06
100	370 7 ab	18 2 a	0.08
300	219 6 c	15.8 b	0.12

Total, 3 beets/pot

H_2S, ppb	Leaves: Fresh wt, g	Leaves: Dry wt, g	Roots, fresh wt, g
0	1242 0 c	126.2 c	643.4 bc
30	2037.6 a	194 0 a	881.0 ab
100	1874.8 ab	176.8 ab	1034.2 a
300	1640 8 abc	137.0 bc	502 2 c

[a] Values followed by different letters are different at the 5% level

Table 5. Effects of Increasing Levels of H_2S on Fresh Weight, Diameter, and Sulfur Content of Dark Green Boston Head Lettuce[a]

H_2S, ppb	Fresh wt, g	Diam, cm	Sulfur as SO_4
0	104 4 x	26.9 x	0.78
30	167.7 y	29.9 y	0.82
100	97.3 x	25.5 x	1.30
300	34.7 z	19.9 z	1.77

[a] Values having different letters are different at the 1% level. Growth period 3/13/76-5/10/76

in growth with 30 ppb H_2S, but reduced growth at the highest level. Dried samples of the lettuce were analyzed for total sulfur and show that additional sulfur accumulated in leaves in direct relationship to the H_2S in the atmosphere. Limited organoleptic tests of flavor of lettuce from control and fumigated treatments showed no differences. A second trial during summer failed to show the growth stimulation with 30 ppb H_2S but a third trial in fall gave a stimulation but the amount was less.

Effects on Douglas Fir. Color of the Douglas fir foliage was not affected by 30 ppb H_2S. All needles remained bright green with no "tip burn." A slight burn was observed with 100 ppb H_2S but 300 ppb caused very extensive foliar injury. This species showed overt injury to the pollutant more clearly than all other plants tested. Growth measurements showed that 300 ppb H_2S caused reduction in growth and dry weight but at 100 ppb these effects were insignificant.

When 50 ppm CO_2 was added to 300 ppb H_2S in the third series of continuous fumigations, the CO_2 overcame some of the growth reduction caused by the H_2S in one crop of head lettuce but not in another. Similar results were shown with sugar beets. Comparisons of the growth reducing effects of 300 ppb of H_2S vs SO_2 on lettuce and sugar beets showed greater effects of H_2S than SO_2. However, a weather front with high humidity, i.e., 80%, in the greenhouse caused extensive foliar injury to sugar beets with SO_2 but none with H_2S.

B. SIMULATED FIELD LEVEL FUMIGATIONS.

To find out whether the actual amounts of H_2S that occur at The Geysers are causing injury to crop plants, potted vines of 'Cabernet Sauvignon' and 'White Riesling' grapes (Vitis vinifera L.) and potted 'Bartlett' pear (Pyrus communis L.) and 'Hartley' English walnut trees (Juglans regia L.) were grown in greenhouses for 2 seasons and fumigated with ambient levels of H_2S, treble ambient H_2S, and amounts of SO_2 equivalent to the treble levels of H_2S.

Procedure

One-year-old rooted cuttings of 'White Riesling' and 'Cabernet Sauvignon' grapevines, 1-year-old 'Hartley' English walnuts on black walnut rootstocks, and 1-year-old 'Bartlett' pear trees grafted on Pyrus betulafolia rootstocks were grown in pots.

Eight separate greenhouses equipped with air conditioning, gas dispensing lines, air sampling lines, wet-dry bulb thermocouples, and irrigation systems were divided into 4 groups of 2 each. Group 1 received carbon-filtered air; group 2, carbon-filtered air plus simulated H_2S concentrations which occur near The Geysers at "Anderson Ridge," the location which receives the highest measured levels of ambient H_2S as recorded by SRI International; group 3, carbon-filtered air plus 3 times the Anderson Ridge levels; and group 4, carbon-filtered air plus amounts of SO_2 equivalent to the H_2S in group 3.

The pollutant levels were programmed on an hourly basis into a dispensing system; i.e., the same levels which occurred each calendar day in 1977 and 1978 were given to the test plants in 1979 and 1980, respectively.

The simulation of these field dosages of H_2S and SO_2 were metered into the various houses for 1 hr at a time, giving a close approximation to the recorded field levels. The treble H_2S and equal levels of SO_2 showed a similar degree of agreement with the projected levels. Five grapevines of each of the 2 cultivars (10 total), 5 pear trees, and 5 walnut trees in 1979 (4 in 1980) were placed in each greenhouse.

The plants were grown for two seasons. For over 90% of the simulated ambient exposure time, the plants received 20 ppb or less of H_2S and only rarely exceeded 20 ppb. The treble H_2S and corresponding SO_2 fumigations were proportionally greater.

Growth parameters for grapes in 1979 included linear growth, all shoots 10 cm or greater; the

weight of prunings removed prior to 1980, total dry weight of leaves, number of flowers, and percent soluble solids in berries as determined by hand refractometer. The same measurements were made in 1980 plus fresh weight of berries and total dry weight of the entire vine including the root ball.

Measurements on pear and walnut trees included total length of shoot growth per tree, number of shoots, dry weight of leaves, total growth as determined by dry weight prunings, and in 1980 the number of flower clusters (pears only) and dry weight of roots.

No visible symptoms of injury occurred on foliage or other plant parts which could be attributed to treatment. None of the parameters measured on the 3 fruit species showed any statistically significant effects caused by the H_2S or SO_2 fumigations over the controls.

These studies show that fumigation in greenhouses for 2 growing seasons of 2 cultivars of grapes, and 1 cultivar each of pears and walnuts, which are grown widely near The Geysers, are unaffected by the highest ambient levels of H_2S that occur in the area, and also treble these levels or amounts of SO_2 equal to the threefold levels.

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