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Effect of Low Concentrations of Ozone and Sulfur Dioxide on Foliage, Growth and Yield of Radish[1]

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Abstract. The radish cv. Cherry Belle was exposed to 5 pphm ozone and/or 5 pphm sulfur dioxide for 40 hr per week for 5 weeks and compared with controls grown in charcoal filtered air. Ozone and/or sulfur dioxide significantly reduced the plant fresh wt, leaf fresh wt, root fresh and dry wt and root length and width. The effects of the combinations of the 2 gases were additive except for plant fresh wt, root length and root fresh and dry weights where the effects were significantly less than additive. Low concns of ozone and sulfur dioxide can be significant factors in the growth and yield of radishes.

Agricultural lands adjacent to urban areas are increasingly exposed to air pollutants of urban origin. The impact of the increasing levels of individual air pollutants on crop growth and yield is poorly understood. The interaction of 2 or more pollutants on plant growth and yield has not been published. Katz (6) found that crop yields were not significantly reduced by sulfur dioxide unless at least 5% of the leaf area was visually injured. Thomas and Hill (12) reported that 40 to 60 pphm sulfur dioxide[5] for 4 hr reduced carbon dioxide assimilation in alfalfa. Katz (5) found that carbon dioxide assimilation was reduced and dark respiration stimulated, when alfalfa was exposed to 10 pphm sulfur dioxide for 504 hr. Examination of the plants revealed a slight shrinkage both in leaf thickness and in individual leaf cells. In some leaves there appeared to be either slight coagulation of the protoplasm or a breakdown of some of the chloroplasts. Guderian and Stratmann (2) have demonstrated a suppression of plant growth by sulfur dioxide with no visible leaf necrosis. Photochemical oxidants, including ozone, have reduced the growth of plants with and without visible injury (10). Oxidants also increased leaf and fruit drop of citrus and thereby reduced the yields by as much as 50% in the Los Angeles area (11). Ozone injury to tobacco has also induced premature senescence which is related to reduced growth (8). Concentrations of ozone incapable of causing visible necrosis in Duckweed reduced frond and floral production (1). Hill and Littlefield (4) observed that 40 to 60 pphm ozone[6] for 0.5 to 1.5 hr reduced apparent photosynthesis 25 to 60% in various crops. In addition, they found that 10 pphm ozone for several hr caused partial stomatal closure of oats with some reduction in stomatal width evident within 0.5 hr after the start of fumigation. Menser and Heggestad (7) found that tobacco leaves were injured by mixtures of ozone and sulfur dioxide at concns that were subthreshold for each gas alone. This syndrome suggested an interaction between ozone and sulfur dioxide in the mixture, that decreased the plant injury threshold.

The objective of this study was to determine if the concns of ozone and sulfur dioxide acting alone or in combination, at concns corresponding to those found in rural areas adjacent to urban complexes, significantly reduced the growth and yield of radishes.

Materials and Methods

Twenty pots (15 cm diameter) containing 5 to 6 radish seeds (*Raphanus sativus,* L., cv. Cherry Belle) planted in a 1:1 mix of peat-perlite were placed in each greenhouse exposure chamber (3). The plants were grown under the following environmental conditions; 25°C day, 20°C night temperature, 80% relative humidity and daylight was supplemented with 1000 ft-c artificial light for 12 hr. The radishes were watered 3 to 4 times per week with a half-strength nutrient solution modified with an iron chelate. Twelve days after seeding, plants were randomly removed from each pot to leave 3 uniformly spaced plants in each pot.

The experimental procedure consisted of 4 exposure treatments of approximately 5 pphm ozone, 5 pphm sulfur dioxide, a mixture of the 2 gases at these concns and a control chamber. The concns of the gases were controlled to within ± 1.5 pphm of the average values shown in Table 1. Air in all chambers was first passed through a particulate and then an activated charcoal filter. The gas treatments were started 3 to 4 days after seeding and were maintained 8 hr per day, 5 days per week until harvest at 5 weeks. The experimental procedure was run twice. Plants in both runs were randomly rotated within chambers and moved between chambers every other day to minimize possible chamber and position effects.

At harvest (5 weeks from seeding) fresh weights of the leaves, roots and whole plants, dry weights of the leaves and roots, and root lengths and widths were determined. The data reported are the average of 3 plants per pot with 20 pots in each treatment. All experimental data were analyzed as a 2^3 factorial with 20 duplicates per treatment by an analysis of variance and significant differences between treatment means illustrated by the method of Least Significant Differences. A plant injury index was constructed for each pot of plants by visually estimating the percent of leaf area showing necrosis or chlorosis.

Ozone, produced by a silent electrical discharge in dry oxygen, and dilute tank sulfur dioxide were separately metered into the exposure chambers. A Davis[7] conductometric analyzer was used to measure sulfur dioxide. Ozone was measured with a

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[5]1 pphm SO_2 = 26.2 $\mu g/M^3$ at 760 mmHg and 25°C.

[6]1 pphm O_3 = 19.6 $\mu g/M^3$ at 760 mmHg and 25°C.

[7]Mention of product or company name does not constitute endorsement by the Environmental Protection Agency or the USDA.

Mast[7] analyzer equipped with a sulfur dioxide scrubber (9) and the readings corrected to 2% neutral buffered KI.

Results and Discussion

Necrotic flecking and upper surface bleaching of interveinal areas developed on leaves of plants exposed to the ozone and combination treatments during the first 2 weeks in both runs. Chlorotic bleaching developed on the upper surface of older exposed leaves near the end of each of the runs in the chambers receiving ozone or the combination treatments. Five to 10% of the leaf area of the cotyledons was injured in the ozone and combination treatments, 3 to 4 days after the start of fumigation in Run 1. However, in Run 2 this amount of injury occurred 8 to 10 days after the ozone and mixed treatments were initiated. This time difference in the appearance of injury probably resulted from the differences in pollutant concns found in the 2 runs. The maximum ozone concns occurred during the first week in Run 1 and during the second week in Run 2.The plant injury indices for all treatments in the 2 runs are shown in Table 1.

Table 1. Pollutant concns and plant injury indices for radishes exposed to ozone and sulfur dioxide. Plants in each run were exposed for 5 weeks.[a]

Treatment	Pollutant concn (ppm) run number		Plant injury index[b] run number	
	1	2	1	2
Control	0	0	0.0	0.0
SO_2	6	5	0.0	0.0
O_3	7	3	1.0	1.0
$O_3 + SO_2$	7 + 5	3 + 5	1.5	2.5

[a]1 pphm O_3 = 19.6 $\mu g/m^3$ and 1 pphm SO_2 = 26.2 $\mu g/m^3$ at 760 mmHg and 25°C.

[b]Plant injury index is based on the avg percent injury to radish plants in 20 pots for each treatment.

The radishes were harvested after 5 weeks of exposure; growth and yield parameters were measured. Means for each of the harvest parameters are shown for each of the treatment combinations in Table 2. The mean squares used to test and assign significant levels are shown in Table 3. The plants in Run 2 were significantly smaller than those in Run 1 except for root fresh wt and root length and width. The 2 runs were made during successive months. This might result in the observed difference in growth.

Even though there were significant growth and yield differences between the 2 runs there were only 5 significant Run x main effect interactions (Table 4). A significant Run x main effect interaction, indicates that the plant response was not the same in the 2 runs. Sulfur dioxide significantly reduced plant and leaf fresh wt in Run 1 but did not affect these same growth parameters in Run 2. There were also significant Run x ozone interactions in root fresh and dry wt and root width. In both runs the ozone significantly reduced plant growth, only the magnitude of the growth reduction for the 3 parameters differed between the 2 runs.

Table 2. Combination means for radishes exposed to low concns of ozone and sulfur dioxide

Combinations	Plant fresh wt (g)	Leaf fresh wt (g)	Leaf dry wt (g)	Root fresh wt (g)	Root dry wt (g)	Root width (cm)	Root length (cm)
Runs							
1.	8.32	6.28	0.43	2.03	0.14	1.01	2.92
2.	7.17	5.20	0.35	1.98	0.11	1.04	2.90
Treatments							
1. Control	9.71	6.53	0.40	3.17	0.18	1.34	3.17
2. SO_2	8.29	6.10	0.41	2.21	0.15	1.11	2.84
3. O_3	6.69	5.22	0.36	1.47	0.09	0.88	2.82
4. SO x O_3	6.30	5.12	0.36	1.18	0.08	0.77	2.82
Run x treatment Combinations							
1 x 1	10.73	7.18	0.46	3.53	0.22	1.38	3.30
1 x 2	8.64	6.36	0.45	2.28	0.17	1.34	2.82
1 x 3	7.35	5.92	0.40	1.44	0.09	0.86	2.82
1 x 4	6.57	5.68	0.40	0.89	0.08	0.65	2.76
2 x 1	8.69	5.88	0.36	2.81	0.15	1.30	3.04
2 x 2	7.94	5.83	0.37	2.15	0.12	1.07	2.87
2 x 3	6.03	4.53	0.32	1.50	0.09	0.91	2.82
2 x 4	6.02	4.56	0.32	1.46	0.09	0.90	2.87

The growth and yield of radish plants exposed to low concns of ozone or sulfur dioxide were significantly reduced except for leaf dry wt which was reduced only by ozone. The growth reductions resulting from the combination of ozone and sulfur dioxide were equal to the additive growth reductions of the single gases for leaf fresh and dry weights and for root width. However, there were significant ozone x sulfur dioxide interactions with respect to plant fresh wt, root length and root fresh and dry wt. These latter growth reductions resulting from the mixed gases were less than would be expected, if the effects of the 2 gases were additive. The less than additive growth reduction of the mixed gases can, when they occur, be seen by comparing the percent growth reductions listed in Table 5. Although some of the growth reductions were less than additive the mixed gas treatments tended to reduce growth more than either pollutant singly.

Plant foliar injury in Runs 1 and 2 ranged from 0 to 2.5% while growth reductions (Table 5) varied from 0 to 63%. Growth reductions of these magnitudes are probably not the result of a simple reduction in the amount of available photosynthetic tissue. The intermittent exposures may have retarded certain critical anabolic processes or accelerated particular catabolic processes without destroying the biochemical mechanisms responsible for them. The intermittent fumigations in these runs might have allowed the plants either to repair injury syndromes or to regain normal metabolic functions within given time limits, when no fumigations were administered. The longer exposures, which often occur under

Table 3. Mean squares of data summarized in Table 2.

Source	df	Plant fresh wt	Leaf fresh wt	Leaf dry wt	Root fresh wt	Root dry wt	Root width	Root length
Run	1	52.8616**	46.8001**	2.3782**	0.1206	0.2249**	0.0064	0.0016
SO_2	1	32.7549**	2.9034*	0.0008	15.5003**	0.1721**	0.1328**	0.1204**
O_3	1	251.1179**	52.1742**	0.9395**	74.8114**	2.1461**	0.6895**	0.1519*
SO_2 x O_3	1	10.5267**	1.1357	0.0023	4.4067*	0.0932*	0.0170	0.1161**
Run x SO_2	1	11.2926**	2.7023*	0.0038	3.0268	0.0188	0.0121	0.0498
Run x O_3	1	1.8204	1.1571	0.0498	5.5007*	0.3794**	0.0529*	0.0289
Run x SO_2 x O_3	1	0.8285	0.6554	0.0014	0.0160	0.0001	0.0097	0.0106
Error	152	1.6877	0.6702	0.0243	0.9071	0.0082	0.0081	0.0133

Significance levels
* = 5%
** = 1%

Table 4. Significant run x treatment interactions of radishes exposed to low concns of ozone and sulfur dioxide[d,e]

Run x treatment	Plant fresh wt (g)	Leaf fresh wt (g)	Root fresh wt (g)	Root dry wt (g)	Root width (cm)
Run 1 x no SO_2	9.04 a	6.55 a			
Run 2 x no SO_2	7.36 bc	5.21 c			
Run 1 x SO_2	7.60 b	6.02 b			
Run 2 x SO_2	6.98 c	5.20 c			
Run 1 x no O_3			2.90 a	0.22 a	0.42 a
Run 2 x no O_3			2.47 b	0.15 b	0.40 a
Run 1 x O_3			1.48 c	0.09 c	0.30 b
Run 2 x O_3			1.16 c	0.09 c	0.25 c

[d]Run x treatment combination means followed by the same letter are not statistically different at the 5% level.

[e]Each value shown is the avg of 2 run x treatment combination means shown in Table 2; i.e: the run 1 x no SO_2 value of 9:04 is the average of the 1 x 1 (10.73) and the 1 x 3 (7.35) means shown in Table 2.

ambient conditions, could eventually result in irreversible changes or to a longer period of reduced photosynthesis or increased respiration and hence larger growth reductions.

The leaf fresh wt showed a smaller percentage reduction than root fresh wt from the same treatments. It is unlikely that the pollutants penetrated the growing media and exerted a direct effect on the roots, therefore, the reduction in root growth was most likely an indirect effect. The pollutant gases probably impaired the metabolism of the leaves and resulted in reduction of photosynthate or some interference with translocation. In either case, the plants had sufficient photosynthate for near normal leaf growth but could not acquire the necessary reserves for normal root growth.

Table 5. Percentage reduction in radish harvest parameters through exposure of plants exposed to ozone and sulfur dioxide.[a]

Treatment	Plant fresh wt	Leaf fresh wt	Leaf dry wt	Root fresh wt	Root dry wt	Root width	Root length
Control	0	0	0	0	0	0	0
SO_2	15	7	0	30	17	17	10
O_3	31	20	10	54	50	34	11
$SO_2 + O_3$	35[b]	22	10	63[b]	55[b]	43	11[b]

[a]The percentage values were calculated from the means shown under treatments in Table 2.

[b]Values are significantly less than additive.

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