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Effect of Ozone on Growth and Assimilate Partitioning in Parsley[1]

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Abstract. **Parsley (*Petroselinum crispum* (Mill.) Nym. cv. Banquet) incurred leaf injury, reduced growth, and altered assimilate partitioning after exposures to 20 pphm ozone. Total plant dry weight and root dry weight were decreased 23% and 43% respectively, with little effect on leaves. The relative growth rate of fumigated plants was reduced after the initial ozone exposure but leveled off at a steady state above that of the control plants when plant dry weights reached about 4.5 g. Ozone appeared to have its greatest effect on growth during initial exposures.**

Plant responses to air pollutants have been described in terms of foliar injury (3, 6, 12), growth (1, 8, 13), and yield (9, 10, 14). These parameters were most often utilized to contrast fumigated and nonfumigated treatments at a single harvest and can therefore be defined as static measurements. Additionally, static measures taken over time have been used to describe growth in terms of cumulative or incremental increases per unit of time. These growth rates, although valuable in determining absolute increases in growth, were rather insensitive to immediate changes in plant response because of their cumulative nature. Any alteration during a specific period in time was influenced by prior growth. Relative growth rates, however, have been used successfully as dynamic measures of plant growth efficiency (4) and were very sensitive measures of alterations in growth. Relative growth rates were measured in terms of units accumulated per initial unit per unit of time and are therefore standardized and independent of the total growth up to a given period.

Bennett and Oshima (2) used root wt ratios (root wt/plant wt) to contrast carrot root responses standardized by relative plant mass, and correlated a quantitative measure of leaf injury (chlorotic leaf dry wt) with decreased root wt in an ozone fumigation study. That study represented an attempt to incorporate growth analysis parameters (4) to measure a pollutant response at harvest. Unfortunately, these parameters were measured only at a single point in time. Bennett (1) utilized relative growth rates to determine plant responses from low levels of oxidant but did not observe differences.

The present study utilized sacrificial harvests over time as a means of monitoring dynamic ozone responses. Relative growth rate (g/g per day) (4), an index of the efficiency of dry wt accumulation, and plant wt ratios, standardized indices of dry wt partitioning, were utilized in the growth analysis. The experiment's objective was to test the effectiveness of these growth analysis parameters to define plant response to ozone exposure.

Materials and Methods

Six 'Banquet' parsley seeds were planted into 7.5 liter pots, 110 pots total, filled with a soil mix of equal parts sandy loam, peat, and redwood chips. Seedlings were thinned to a single plant per pot after the first mature leaf expanded and the population was randomly divided into 2 treatments. Plants were grown in a large carbon filtered greenhouse for 62 days before the initiation of the experiment using a weekly rotation within the greenhouse to maximize uniformity. A random selection of 6 plants was harvested 7 days before ozone exposures were initiated to provide baseline data to characterize plant growth. Six plants from both the fumigated and control treatments were then harvested at 7-day intervals throughout the 8-week exposures to monitor plant responses. The remaining 8 plants, included in the treatments as a precaution against accidental loss, were discarded after the final harvest.

Ozone exposures at 20 pphm (392 $\mu g/m^3$) for 4 hr were initiated after 67 days of growth every Monday and Friday for a period of 8 weeks. Parsley was slow in establishing itself and the 67-day period was allowed to ensure against seedling mortality. Plants were fumigated in 1.23 × 1.23 × 0.62 m wood-framed, tedlar covered fumigation chambers. Ozone was generated by passing oxygen over high voltage argon lamps and metered into the chamber after dilution with carbon filtered air. Exposures were monitored with a DASIBI model 1003-AH ozone instrument calibrated by ultraviolet photometry. Greenhouse temp ranged between 23° to 30°C during the day and were maintained at a min of 18° at night by steam heaters. Relative humidity fluctuated with the efficiency of the evaporative coolers within a range of 20 to 60%.

Dry wt of roots and leaves were recorded after oven drying at 60°C for 3 days. Roots were washed carefully to eliminate potting media before drying. Counts of injured leaves included ozone injury, senescence, and mechanical injury. Mean relative growth rates (RGR) were calculated from the formula discussed by Radford (11).

Results

Foliar injury occurred on the mature compound leaves of ozone fumigated parsley after the first exposure. Symptoms were similar to those previously described on carrot (2) with interveinal chlorosis occurring on older leaflets and light mottling on younger tissue. After the first fumigation 86% of the leaves were injured followed by fluctuations between 79 and 62% due to continuous growth and new injury in subsequent harvests (Table 1). The no. and max length of leaves of plants in the 2 treatments did not vary greatly over the 8-week period although some divergences were significant. The fumigated plants had produced significantly more leaves by the 8th harvest although their biomass and max leaf length were equivalent to the control plants.

The ozone exposures reduced root and total plant growth in terms of dry wt but did not produce an equivalent reduction in the leaves (Fig. 1). The leaf, root, and total plant growth were well defined as log functions with statistically identical slopes. This suggested that ozone had the greatest effect on growth after the initial fumigation, followed by comparable

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Table 1. Effect of ozone on parsley leaves.

Harvest	Ozone (pphm)	Leaves Number	Length[1] (cm/plant)	Chlorotic[2] (%/plant)
0[3]	0	4.8[4]	11.2	0.0
1	0	5.8	14.5	0.0
	20	6.0	13.8	86.3
2	0	9.5	18.0	10.6
	20	9.0	17.2	74.2
3	0	11.6	20.3*	6.0
	20	10.3	17.7	74.2
4	0	13.3*	21.5	7.3
	20	11.2	20.2	79.2
5	0	14.6	21.3*	7.0
	20	14.2	19.2	76.5
6	0	16.7	21.8	5.2
	20	17.3	23.0	62.1
7	0	20.5	22.2	8.5
	20	20.3	24.2	65.3
8	0	22.0*	23.0	10.5
	20	25.7	23.2	69.8

[1]Length of largest leaf.

[2]Percentage of ozone injured or senescent leaves.

[3]Baseline harvest taken before fumigations were initiated.

*Indicates significant differences between ozone treatments, 5% level.

dry wt accumulation. An analysis of RGRs substantiated the ozone effect on early growth. Ozone severely reduced the growth efficiency of the fumigated plants during the first 2 weeks (Fig. 2A) of exposure. The exposures induced a fluctuation of RGRs until a steady state was initiated at 4.5 g total dry wt. This was in sharp contrast with the normal gradual decline in RGRs of the nonfumigated parsley.

A contrast of the partitioned RGRs for the roots and leaves of fumigated plants revealed that the roots were the most affected early in the experiment and the leaves actually had a greater RGR than the plant as a whole during a significant period of growth (Fig. 2B, 2C). Both partitioned portions demonstrated the early fluctuations observed in the plant RGRs until plant dry wt reached about 3.3 g. At this point

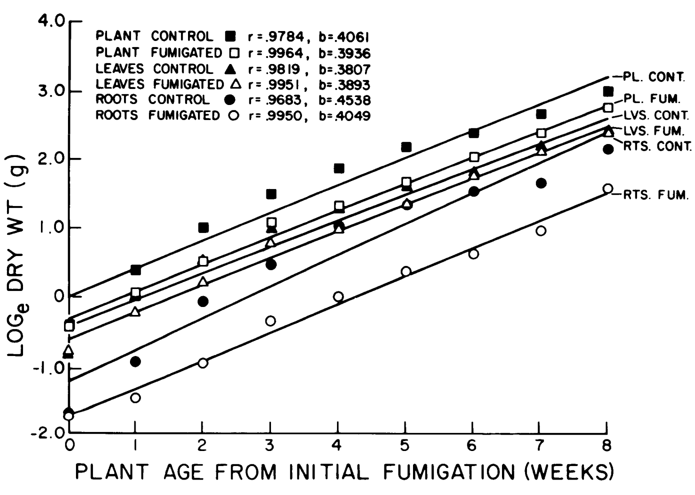

Fig. 1. Plant and partitioned root and leaf growth of ozone fumigated and nonfumigated parsley. All slopes were statistically equivalent (5% level).

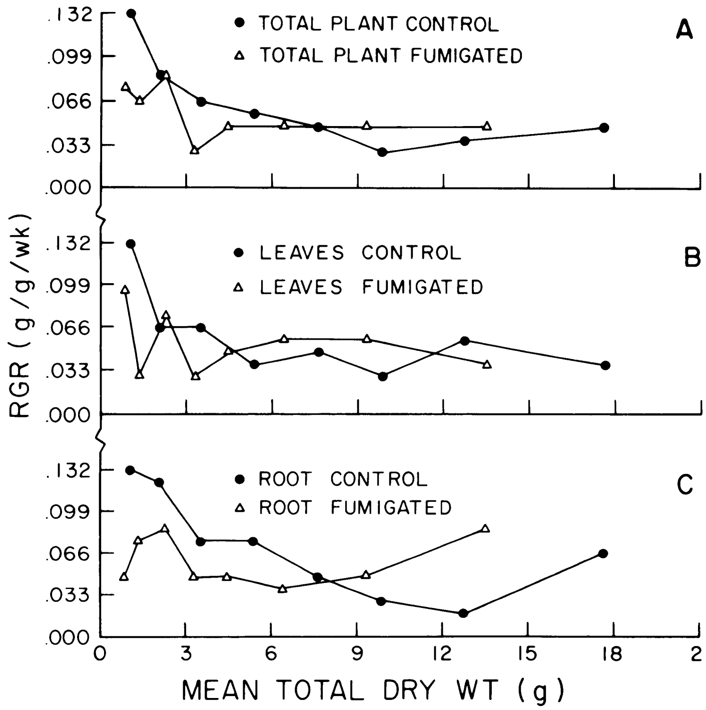

Fig. 2. Plant and partitioned root and leaf relative growth rates (RGR) of ozone fumigated and nonfumigated parsley.

growth efficiency increased in the leaves, apparently at the expense of the roots. This shift in growth efficiency reverses itself during the later stages of the experiment when the root RGR increases and the leaf RGR decreases. The sequential partitioning of growth efficiency in the fumigated plants was ultimately expressed as a steady state RGR in terms of the total plant.

The root wt ratios (root dry wt/plant dry wt) also reflected the early impact of ozone on fumigated parsley (Fig. 3). Differences in root wt ratios were observed at first harvest. The divergence between fumigated and control root wt ratios increased until the fourth harvest. Control parsley appeared

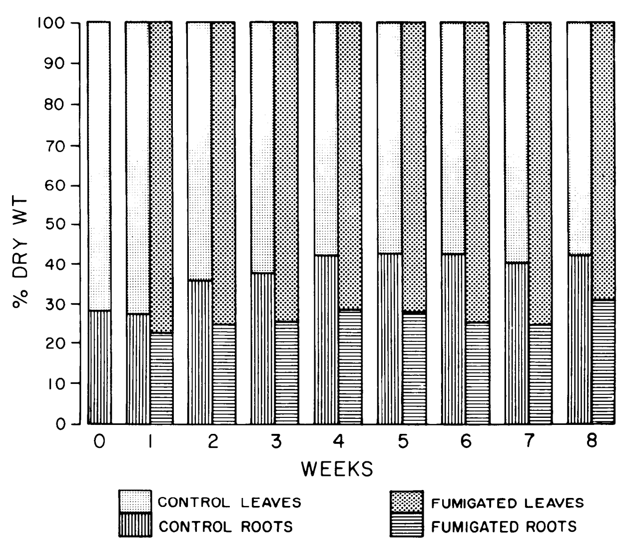

Fig. 3. Plant wt ratios of ozone fumigated and nonfumigated parsley. Reductions in root wt ratios were significantly different (5% level) for weeks 1-8. Week 0 reflects the pre-exposure plant wt ratio.

to stabilize with root systems accounting for 42% of the plants' dry wt while fumigated plant roots ranged between 24 to 30% of the plant.

Reductions of root and plant dry wt from ozone were closely correlated with dry wt of injured leaves (leaf dry wt × % injured leaves) during the earlier period of the experiment. The plant growth reduction from control plants was correlated through the fifth harvest (r = .98**) and the root reduction through the sixth harvest (r = .98**). The deterioration of this relationship appeared to coincide with the elevation of fumigated root and plant RGRs above the controls.

Discussion

Two phases of plant response to ozone were observed in parsley. The first appeared to be a period of growth repression characterized by fluctuations in growth efficiency. The second phase would be best described as a period of accommodation characterized by a steady state RGR. The steady state level was a product of sequential increases in the growth efficiencies of the roots and leaves. The effect of both phases on the total growth of ozone fumigated parsley was an early reduction in accumulated dry matter followed by an extension of the log phases of growth. The growth curves for parsley were indicative of this as the growth of fumigated plants more closely fit the log functions.

The leaves, actual site of ozone injury, had apparent priority over the roots in the partitioning of assimilates. They were first to increase growth efficiency during the accommodation phase of response and were not significantly affected by ozone in terms of dry matter accumulation. The fumigated parsley produced a significantly greater no. of leaves by the final harvest. This apparent stimulation has been observed in other species under pollutant stress (1, 2). Studies of plants under assimilate deficiency (5) or lower light intensities (7) indicate a priority of shoot growth over that of the root.

Close examination of the pollution stress-root growth relationship revealed a possible explanation for the inhibition of root growth. Ozone most severely injured mature lower leaves, the organs which act as the main source of photosynthates for root growth (15). The immediate reduction of root RGR and change in partitioned dry matter described by the root wt ratio after ozone exposure appeared to substantiate this effect in parsley. This may not be the case with fruiting plants where the reproductive organs also act as a strong sink.

Although incremental RGRs were found to be a sensitive monitor of ozone induced plant stress, the characterization of a mean RGR for overall plant growth efficiency would have limited value. The interruptive nature of ozone stress would be masked if a regression slope were used to characterize growth efficiency. The regression method would appear to be most useful in experiments where treatments produce changes in slopes. In contrast, the growth of both the ozone fumigated plants and their partitioned parts fitted functions with statistically identical slopes.

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