

The Effect of Acute Ozone Exposures on the Growth of Hybrid Poplar

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ABSTRACT

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Rooted cuttings of hybrid poplar (*Populus maximowiczii* × *P. trichocarpa*, clone 388) were exposed in a controlled chamber to 400 µg/m³ of ozone for 5 hr two, three, four, or five times during a 1-mo period. About 60–80% of the leaves developed toxicity symptoms on 10–25% of the total leaf area. Ozone had no statistically significant effect on total dry weight, leaf area, elongation, relative growth rate, or net assimilation rate of the total plant population, but the trend was toward a reduction in each of these variables. A few individuals were more susceptible than the majority, and their growth was obviously inhibited.

Additional key words: air pollution, oxidant

Sufficient evidence exists to prove that ozone can reduce the yield of agricultural crops in areas of the United States with elevated ozone levels (2), but the effect of ozone on trees has not been as clearly established. Few experiments have been conducted under field conditions. In California, Thompson and Taylor (32) and Thompson et al (31) reported a reduction in yield of navel orange and lemon trees grown in ambient air compared with trees grown in charcoal-filtered air. Studies in the San Bernardino Mountains indicated that oxidant pollution may be depressing the growth of forest trees, but the hypothesis has not been rigorously tested (2). Santamour (29) reported that average height of *Platanus* seedlings was 25% less in ambient air than in charcoal-filtered air in Beltsville, MD. Skelly (30) reported that oxidant pollution may be depressing or stimulating tree growth in Virginia.

Most experiments with trees have been conducted in controlled chambers with ozone (O₃) dosages that are unlikely to occur in the field (Table 1). Notwithstanding the high dosages, tree growth

was unaffected by ozone in 20 cases, stimulated in three cases, and decreased in eight cases. Linear extension or biomass was used as the criterion of growth.

In New Brunswick, NJ, hybrid poplar trees, clone 388, were grown from 1975 to 1979 in an unfiltered and in a charcoal-filtered, open-top chamber (5,17). No significant difference between filtered and unfiltered air treatments was found

in the linear growth in any year or in biomass in the 1 yr that it was measured, despite the occurrence of ozone levels high enough to produce symptoms on herbaceous species and decrease their growth (I. Leone, unpublished).

To evaluate the response of hybrid poplar to ozone under laboratory conditions, we exposed hybrid poplar trees in a controlled chamber to acute but discontinuous doses of ozone, such as might occur in the most severe pollution episodes in urban areas of the eastern United States (7,22).

MATERIALS AND METHODS

Plant material. Hybrid poplar (*Populus maximowiczii* × *P. trichocarpa*), clone 388, was selected for the study because, according to Wood and Coppolino (33), it is one of the more ozone-sensitive tree species, having exhibited symptoms of ozone toxicity in controlled-chamber studies at 0.25 ppm for 8 hr. Rooted cuttings were placed in 18 plastic pots (5 L) containing a potting mix (loam, peat,

Table 1. Reported effect of ozone exposures in controlled chambers on tree growth

Concentration (ppm)	Duration	No effect	Decrease	Increase	Reference
0.30	8 hr/day, 5 days/wk, 20 wk	Tulip poplar	Sycamore		(9) ^a
		Green ash	Sugar maple		
		White ash	Silver maple		
		Red maple			
		Black walnut			
0.15	8 hr/day, 5 days/wk, 6 wk		Hybrid poplar		(10) ^{a,b}
0.25	8 hr/day, 5 days/wk, 6 wk	Paper birch			(11) ^a
		Yellow birch			
		Big aspen			
		Cottonwood			
		Japanese larch			
0.10	6 hr/day, 7 days/wk, 22 wk	Douglas fir	Ponderosa pine		(2) ^{a,b}
		Jeffrey pine	Western white pine		
		Lodgepole pine			
		Shore pine			
		Sugar pine			
		Sitka spruce			
0.10–0.40	6 hr/4 days, 7 days/wk, 4 wk		Tamarix juniper	Pfitzer juniper	(16) ^a
				Arborvitae	
0.45	3 hr/day, 2 days/wk, 19 wk	Troyer citrange			(19) ^{a,b}
0.10–0.40	4 hr/wk, 9 wk	White ash			(18) ^{a,b}
		Black cherry			
0.90	5 hr		American elm		(1) ^c

^aLinear growth measurement.

^bBiomass measurement.

^cStem growth measurement.

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and vermiculite; 1:1:1) and were kept in a filtered-air greenhouse. Plants were given Osmocote (18-6-12) at the rate of 16 g per pot per month to provide a nutrient status that enhanced ozone susceptibility (4,6). Natural light was supplemented by fluorescent and incandescent light (7.9 mW/cm²) from 1650 to 2400 hr. Cuttings were thinned to three per pot at the start of the experiment.

Ozone fumigations. Two similar experiments were conducted, one in December–January and the second in February–March. Plants were exposed to ozone at 400 µg/m³ for 5 hr three, four, or five times over a 1-mo period in the first experiment and two, three, or four times during a 1-mo period in the second experiment. Fifteen plants per treatment were exposed to 21.8 C and 73% relative humidity (experiment 1) or 12 plants per treatment were exposed to 25.5 C and 75% relative humidity (experiment 2) from 0900 to 1500 hr at 1-wk intervals in a dynamic flow chamber that has been described previously (15). All plants were returned to an air-filtered greenhouse after each ozone exposure.

This acute type of fumigation was selected because it simulates the ambient conditions in New Jersey better than a chronic, long-term exposure. In addition, it is generally well accepted that sporadic peaks are more important in causing visible foliar injury and in reducing plant growth than accumulated low doses (2).

Table 2. Percentage of hybrid poplar leaves with ozone toxicity symptoms after exposure to ozone

Number of ozone exposures	Injury after consecutive exposures				
	1	2	3	4	5
Experiment 1					
3	63	70	65
4	67	65	70	52	...
5	61	78	80	73	71
Experiment 2					
2	65	68
3	75	65	61
4	63	60	63	64	...

On a polluted day, the oxidant level is low in the morning (0.03 ppm), begins to rise at 1100 hr, peaks at about 1600 hr, and returns to a low level during the evening. During 1980, the maximum hourly average in New Jersey ranged from 0.13 to 0.23 ppm, depending on the location, and a concentration of 0.08 ppm (the federal air quality standard before 1979) was exceeded not more than 5% of the time (22). According to data collected by a regional network for air pollution monitoring (7), a significant study that incorporated both biological and chemical monitors, other northeastern states also experience similar sporadic or fluctuating peaks rather than sustained high concentrations. At eight sites in the Northeast, 0.15 ppm occurred less than 1% of the time in the summers of 1970–1972.

Data collection and analysis. At the start of the experiment, six representative cuttings were harvested to determine the initial height, dry weight, and leaf area needed to calculate mean relative growth rate and net assimilation rate. Only aboveground plant tissue was harvested. After 7 wk, the same measurements were taken for treated cuttings.

The area of hybrid poplar leaves, measured as described by Harkov (3), was used to develop the following regression formula, based on final leaf dry weight: LA = 81.189DW + 225.032, where LA is leaf area measured in square centimeters and DW is final leaf dry weight measured in grams ($r^2 = 0.98$). This equation is based on data for 75 hybrid poplar trees 10–12 wk old, and the standard error about the predicted leaf area mean was ±34 cm². The leaf area of test plants was determined from this formula. The mean relative growth rate and mean net assimilation rate were determined as described by Radford (27).

Each week, height growth measurements were recorded for all plants. After each exposure of the plants to ozone, the percentage of leaves with toxicity symptoms was estimated and recorded. All values were subjected to analysis of

variance (ANOVA) and compared, when appropriate, by Tukey's test for significance at the $q = 0.05$ level (20).

RESULTS

Ozone toxicity symptoms, consisting of interveinal dark brown to black stipple and bifacial necrosis, developed on 52–80% of the hybrid poplar leaves after three to five exposures to ozone at 400 µg/m³ for 5 hr over a 1-mo period in experiment 1 and on 60–75% of leaves after two to four exposures in experiment 2 (Table 2). In each series of fumigations in experiment 2, a few individuals were more sensitive than the majority and showed symptoms on as much as half their leaf area.

When the population was considered as a whole, ozone exposure did not significantly affect height, dry weight, leaf area, mean relative growth rate, or mean net assimilation rate in either experiment (Table 3), although the trend was toward a reduction in each variable. Data for the three most sensitive individuals revealed a significant decrease in all growth variables.

DISCUSSION

Despite the use of clonal material and the selection of apparently uniform cuttings for the two experiments, the response of individuals varied considerably in a given ozone fumigation. In a previous experiment, Kohut et al (13) reported similar variability in foliar symptoms caused by ozone in this same clone. Such variability might have been expected if hybrid poplar cuttings had been taken from different positions on a single tree or from many trees and thus had different physiologic activity.

The growth of most plants in our experiments was not decreased, despite extensive visible symptoms. A few individuals were more sensitive than the general population, and their growth was indeed inhibited. Both the mean relative growth rate and mean net assimilation rate values for control and exposed plants were within the normal range reported

Table 3. Growth measurements of hybrid poplar population (P) and three most sensitive individuals (I) after multiple exposures to ozone at 400 µg/m³ for 5 hr

No. of exposures	Growth measurement ^a													
	SW (g)		LW (g)		Total DW (g)		Height (cm)		LA (cm ²)		RGR (g g ⁻¹ wk ⁻¹)		NAR (g cm ⁻² wk ⁻¹)	
	P ^b	I	P ^b	I	P ^b	I	P ^b	I	P ^b	I	P ^b	I	P ^b	I
Experiment 1														
0	1.36	...	2.40	...	7.76	...	58.8	...	620	...	0.24	...	0.0012	...
3	1.09	0.45	1.91	0.79	3.00	1.24	57.2	45.3	503	230	0.20	0.10	0.0010	0.0004
4	0.97	0.43	1.63	0.69	2.60	1.13	54.5	43.0	414	172	0.18	0.09	0.0009	0.0004
5	0.84	0.29	1.45	0.48	2.30	0.76	51.3	38.0	380	135	0.17	0.05	0.0008	0.0002
Experiment 2														
0	2.28	...	5.42	...	7.70	...	64.3	...	1,300	...	0.32	...	0.0018	...
2	2.16	...	4.70	...	6.86	...	64.3	...	1,139	...	0.30	...	0.0017	...
3	2.17	...	4.81	...	6.99	...	63.8	...	1,143	...	0.31	...	0.0017	...
4	1.89	...	3.87	...	5.76	...	62.1	...	951	...	0.28	...	0.0015	...

^aSW = stem weight; LW = leaf weight; DW = dry weight; LA = leaf area; RGR = mean relative growth rate; NAR = mean net assimilation rate.

^bMeans within columns do not differ, according to Tukey's test for significance at the $q = 0.05$ level.

for other poplar species (8,21,25).

Inasmuch as total dry weight also showed no difference between control and exposed plants, we agree with Oshima et al (23) that the simpler measurement is as useful as the mean relative growth rate. Our results confirm the report that the mean net assimilation rate is not a very sensitive measure of a plant's response to environmental change (26).

Leaf area appeared to be more sensitive to ozone, corroborating observations made by other researchers (12,24). A reduction in leaf area would not necessarily prove injurious to a plant if it were accompanied by increased assimilative capacity. Unlike the growth of some agricultural plants, tree growth is correlated more closely with utilization of photosynthates than with production of photosynthates. A large loss of photosynthetic leaf area can occur without significantly affecting tree growth. Kulman (14) reported that 50% mechanical defoliation of hybrid poplar decreased annual incremental growth by only 3.7%.

Our results with hybrid poplar agree with the majority of published reports that have shown that ozone exposures in controlled chambers have little effect on tree growth (Table 1). These previous studies included 16 species that had been evaluated as sensitive or resistant to ozone based on visible symptom development. Green ash, white ash, tulip poplar, Monterey pine, and Jeffrey pine, which have been cited in the literature as ozone-sensitive, showed no growth reduction. Our results disagree with those of Jensen and Dochinger (10) for hybrid clones 207 and 211 (Table 1), but the high dosages (0.15 ppm ozone for 8 hr per day, 5 days per week for 6 wk) that they tested would be unlikely to occur in the Northeast.

Inasmuch as no significant decrease in growth occurred in most trees when as many as half the leaves were visibly injured, we think it reasonable to assume as a general rule that hybrid poplar growing in a polluted urban environment like New Jersey is not sustaining any decrease in growth. Although it is certainly possible that background ozone levels may sensitize trees to higher

pollution peaks in the field, thus enhancing growth effects, there is no evidence to support this notion. In a recent field survey, we saw symptoms on only a half-dozen leaves of a single hybrid poplar tree (28). The few sensitive individuals detected in our experiment may well have their counterparts in the field, but we believe that these are exceptions that tend to prove the rule.

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