SENSITIVITY OF RED MAPLE CULTIVARS TO ACUTE AND CHRONIC EXPOSURES OF OZONE

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Abstract. Five red maple (*Acer rubrum*) cultivars, 'Autumn Flame', 'Fairview Flame', 'Franksred' (Red Sunset™), 'Northfire' and 'October Glory', and 1 Freeman maple cultivar (*Acer* ∞ *freemanii* 'Autumn Blaze', an interspecific cross between red maple and silver maple) were exposed to 0, 100, 200, or 300 ppb ozone for 4 hours on 2 consecutive days. Visible foliar injury, characterized as a stipple on the upper leaf surface, was observed in all ozone treatments except the control, and occurred on the oldest leaves only. 'Autumn Flame' had the least visible injury (less than 1% of the leaves injured), while 'Northfire' had the most (4% of the leaves injured). In a chronic ozone exposure experiment, 3 red maple cultivars ('Autumn Flame', 'Fairview Flame', and 'October Glory'), and 1 Freeman maple cultivar ('Autumn Blaze') were exposed to sub-ambient, ambient, or twice-ambient ozone levels for 9 weeks. No visible foliar injury developed in any of the ozone treatments. No differences for plants in the 3 ozone treatments occurred for height, caliper, leaf, shoot, or root dry weight. Photosynthesis was lower for sub-ambient plants and similar for twice-ambient and ambient plants 4 weeks after treatment initiation, while at 8 weeks no differences occurred. These data indicate that red maple cultivars are relatively tolerant to elevated acute and chronic ozone exposures.

Selection of superior species for use as street or landscape trees involves the consideration of numerous qualities such as flowering, fruiting, and/or fall color. Growth habit and rate are important as are insect and disease resistance and tolerance to air pollutants. Red maple (*Acer rubrum*) is commonly used as a street tree throughout the United States (13). It has a native range from southeastern Manitoba to eastern Newfoundland, south to Florida, and west to eastern Texas—the greatest north-south distribution of all tree species along the east coast of the United States (18). This distribution offers climatic variation and geographic distances essential for genetic differentiation (23). Cultivars that have performed well in the southeastern United States include 'Armstrong', 'Autumn Flame', 'Autumn Blaze', 'Bowhall', 'Gerling', 'Franksred' (Red Sunset™), and 'October Glory' (2,4,26,31).

Since being identified as a phytotoxic air pollutant in the 1950s (20), ozone has progressively become the major air pollutant across the United States. Tropospheric ozone is associated with urban areas that have many automobiles; however, it is readily transported long distances to non-urban areas (30). The major effects of ozone on terrestrial vegetation include visible foliar injury, and reductions in growth, productivity, and crop quality (19,24). Acute ozone exposures (the exposure to high concentrations for short periods of time) and chronic ozone exposures (the exposure to low concentrations for long periods of time) can result in injury to sensitive plant species under certain environmental conditions. In general, environmental conditions that favor plant growth tend to increase a plant's sensitivity to air pollutants (15). The critical concentrations of pollutants that injure various plant species and cultivars are modified by factors that influence opening and closing of stomata such as light intensity, water supply, relative humidity, and temperature (14). Symptoms on broadleaved plants typically consist of foliar chlorosis, fleck, stipple, and uni- and bifacial necrosis (15). Visible injury from acute exposures to ozone has been reported on a wide variety of tree species including white ash (*Fraxinus americana*), honeylocust (*Gleditsia triacanthos inermis*), London planetree (*Platanus* ∞ *acerifolia*), English oak (*Quercus robur*), yellow poplar (*Liriodendron tulipifera*), and black cherry (*Prunus*

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serotina) (1,11,28). Red maple seedlings have demonstrated tolerance to ozone and intermediate tolerance to sulfur dioxide (14). Variation in sensitivity to ozone, but not in the type of injury, was noted among red maples from 4 seed sources (29). Differences in ozone sensitivity among cultivars have been reported in landscape plants such as azaleas (*Rhododendron*) (6), trembling aspen (*Populus tremuloides*) (12), and white pine (*Pinus strobus*) (5). The objective of this study was to determine the relative sensitivity to acute and chronic exposures of ozone of several red maple cultivars proven to be good performers in southeastern United States.

Materials and Methods

Acute exposure. One-year-old liners, 45 to 51 cm tall, of *Acer rubrum* 'Autumn Flame', 'Franksred' (Red Sunset™), 'October Glory', 'Fairview Flame', 'Northfire', and *Acer* ∞ *freemanii* 'Autumn Blaze', a Freeman maple, were transplanted into 2.7 L pots containing a pine bark/sand medium (7:1 by volume) in April 1995. The medium was amended per m^3 with 4.7 kg 22N-2.6P-11.6K (24-4-12) Polyon (Pursell Industries, Sylacauga, Alabama), 0.9 kg Micromax (The Scotts Company, Marysville, Ohio) and 3.0 kg dolomitic limestone. Plants were grown on a gravel container bed with overhead irrigation provided twice daily for 30 minutes per application.

Trees were selected for uniformity and placed into 1 of 4 blocks in May 1995. Within each block, 2 plants per cultivar were assigned to 1 of 4 ozone treatments, resulting in 8 plants per cultivar exposed to each ozone treatment. Ozone concentrations of 0, 100, 200, or 300 ppb were applied for 4 hours on each of 2 consecutive days in continuously stirred tank reactors (CSTRs) located within a walk-in growth chamber (7). Because only 4 CSTRs were available, treatments were replicated over time. Concentrations used in this study, except for 300 ppb, were similar to levels reported during the summer in Atlanta, Georgia, and Birmingham, Alabama (16,17). Photosynthetic photon flux (PPF) within the CSTRs at canopy level was 730 ± 16 µmol/m^2/s. Temperature and relative humidity during the exposure were 26 ± 3°C and 70 ± 4%, respectively.

Ozone was generated by passing pure oxygen through a high-intensity electrical discharge source (Ozone Research and Equipment Corporation, Phoenix, Arizona). Ozone concentrations were monitored continuously with a UV Photometric Ozone Analyzer (Thermo Environmental Instruments, Inc. Hopkinton, Massachusetts) during exposures. Air was filtered through activated carbon prior to ozone addition to help maintain uniform concentrations within the CSTRs.

Trees were watered before and after each exposure period to avoid drought stress. After exposure, plants were returned to the gravel container area and evaluated 2, 7, and 30 days later for percentage of leaves injured (PLI) and leaf area injured. Leaf area injured was rated for those leaves with visible injury using the Horsfall-Barratt foliar injury scale (H-B rating) (9). This scale ranges from 1 (no injury) to 12 (100% of the leaf area injured). PLI and H-B rating were averaged for each block by treatment and cultivar before analysis. All data were arc-sine transformed prior to performing analysis of variance (ANOVA); retransformed data are presented. Differences among cultivars were compared using Duncan's multiple range test at $P = 0.05$.

Chronic exposure. One-year-old liners, 45 to 51 cm tall, of 'Autumn Flame', 'Franksred' (Red Sunset™), 'Fairview Flame', and 'Autumn Blaze', were transplanted into 15.1 L pots containing an amended pine bark/sand medium (7:1 by volume) in April 1995. Plants were grown on a gravel container bed with overhead irrigation provided twice daily for 30 minutes per application.

Ozone treatments consisted of sub-ambient (CF) air, in which air was filtered through activated carbon to reduce ozone about 50% below ambient level; nonfiltered ambient (NF) air (Auburn, Alabama, classified as a rural setting); and air injected with ozone at 2.0X ambient. These treatments were injected into 6 open-top 4.6m by 3.5m (diameter ∞ height) fumigation chambers (8) arranged in 2 blocks, with a total of 2 chambers used for each treatment.

Ozone was generated by passing pure oxygen through a high-intensity electrical discharge source (Griffen, Inc., Lodi, New York) and added to the chambers 12 hours per day (9:00 A.M. to 9:00 P.M.),

Table 1. Ozone 12-hour treatment means[z], SUM0[y], SUM06[x], and the number of hours above 120 ppb.

	Treatment		
	Sub-ambient (CF)	Ambient (NF)	2.0X ambient (2.0X)
12-hour mean (ppb)	26.9 ± 7	41.7 ± 6	92.5 ± 15
SUM0 (ppm-h)	4.0 ± 2	5.6 ± 2	10.4 ± 3
SUM06 (ppm-h)	0	1.1 ± 1	8.1 ± 5
No. hr > 120 ppb	0	0	28.7 ± 12

[z]12-hour (9:00 A.M. to 9:00 P.M.) ozone treatment means.

[y]SUM0 24-hour sum of all hourly ozone concentrations.

[x]SUM06 24-hour sum of all hourly ozone concentrations ⊕ 60 ppb.

7 days per week. Fans were turned off from 11:00 P.M. to 6:00 A.M. to permit natural dew formation within the chambers. Within each chamber, ozone concentrations were continuously monitored using a U.S. EPA approved monitor (Thermo Environmental Instruments, Hopkinton, Massachusetts). Each chamber was monitored for 2 minutes every half hour with continuous adjustments. An air exchange rate of 2 exchanges per minute facilitated mixing and cooling within a chamber. To characterize ozone exposures within each treatment, ozone 12-hour (9:00 A.M. to 9:00 P.M.) treatment means, SUM0 values (24-hour sum of hourly average ozone concentrations), SUM06 values (24-hour sum of hourly averages equal to or above 60 ppb), and the number of hours equal to or above the 120 ppb National Ambient Air Quality Standard for ozone (30) are presented in Table 1.

Plants were evaluated for visible foliar injury 4 and 8 weeks after ozone exposure began (WEB), in their respective chambers using the same rating system used in the acute experiment. In addition, height and caliper were measured 4, 6, and 8 WEB, respectively. On August 12, all plants of each cultivar were harvested, and roots, stems, and leaves were separated. Individual plant components were dried for 72 hours at 70°C and then weighed.

Four and 8 WEB, gas exchange evaluations consisting of net photosynthesis (Pn), transpiration (E), and stomatal conductance (Cs) were determined using a portable photosynthesis system (Model LI-6250, LI-Cor Inc., Lincoln, Nebraska) in a closed mode (22). This setting allowed 12.3 cm^2 of a leaf to decrease the CO_2 concentration in a 1-L chamber over a 20-second period. Photosynthetically active radiation (PAR) levels were monitored with a quantum sensor (Model LI-190, LI-COR, Lincoln, Nebraska) attached to the plexiglass chamber. Gas exchange measurements were made on 3 leaves on each tree for each cultivar. Measurements were made nondestructively on attached, mature leaves in full sun at the midpoint of current season's growth. Within each replication, CO_2 concentrations ranged from 330 to 390 mg/L and leaf temperatures were approximately 32°C. Measurements were taken from 9:30 A.M. until 2:30 P.M. at an average PAR level of 1890 $\mu mol/m^2s$. Data were subjected to (ANOVA). Mean separations were determined by Duncan's multiple range test at P = 0.05.

Results and Discussion

Acute exposure. Ozone x cultivar interactions were not significant; hence, only main effects are presented. Minor visible foliar injury was observed on all red maple cultivars following exposure to all ozone concentrations except the control. Visible injury occurred on the oldest leaves only and was characterized as stipples on the upper leaf surface and consisted of discrete groups of pigmented cells. Injury symptoms did not progress between 2 and 30 days after exposure. Therefore, only data collected 2 days after exposure is reported. Injury was minor, involving less than 6.2% of the leaves (PLI), and less than 2.1% of the leaf area (H-B rating) (Table 2).

Across all cultivars tested, the percentage of leaves injured (PLI) increased linearly as ozone concentration increased. PLI increased from 0% in the control to 6.2% in the highest ozone concentration, 300 ppb. H-B rating, which is used to evaluate visible injury, increased quadratically as ozone concentrations increased. H-B ratings increased from 1.0 (0% of the leaf area injured) in the control to 2.1 (3% to 6% of the leaf area injured) at the highest concentration, 300 ppb.

'Northfire' had the highest PLI of 4.0%, which was 13 times that of 'Autumn Flame' (0.3% PLI), the least injured cultivar. Injury levels were similar for 'Northfire', 'Fairview Flame', 'October Glory',

Table 2. Percentage of the leaves injured (PLI) and Horsfall-Barratt (H-B) rating for foliar injury for 6 red maple cultivars exposed to 4 acute levels of ozone.

Cultivar	PLI[z]	H-B rating
Autumn Blaze[y]	1.9ab[x]	1.5b
Autumn Flame	0.3b	1.1c
Fairview Flame	3.4a	1.6ab
Franksred (Red Sunset™)	1.8ab	1.4b
Northfire	4.0a	1.8a
October Glory	2.9a	1.6ab
Ozone Concentration (ppb)		
0[w]	0.0	1.0
100	0.9	1.3
200	2.5	1.6
300	6.2	2.1
Significance[v]	L***	Q**

[z]Cv. x O_3 not significant; hence, only main effects are reported. PLI and H-B rating data were transformed using an arc-sin transformation before analysis. Retransformed mean values are presented. H-B ratings: 1 = 0%, 2 = 1% to 3%, 3 = 3% to 6% of the leaf area injured.

[y]PLI and H-B rating are across ozone concentrations.

[x]Mean separation within rows by Duncan's multiple range test, P = 0.05.

[w]PLI and H-B rating are across cultivars.

[v]Linear or quadratic response significant at the 1% (**) or 0.1%(***) level.

'Autumn Blaze', and 'Franksred' (Red Sunset™). Among all cultivars, the PLI observed at the highest concentration was less than 3.5% of the leaves. 'Northfire' with an H-B rating of 1.8 (3% to 6% of the leaf area injured) was similar to 'Fairview Flame' and 'October Glory', both with H-B ratings of 1.6, had the most injury, while 'Autumn Flame' had the least with an H-B rating of 1.1 (1% to 3% of the leaf area injured).

These results are similar to those from other studies conducted in the northeastern United States demonstrating the relative high tolerance of red maple cultivars to elevated ozone concentrations. Karnosky (11) reported that after exposure to 500 ppb ozone for one 7.5-hour period, 'Autumn Flame' and 'Red Sunset' exhibited no injury, 'Tilford' had very slight injury, and 'Bowhall' had intermediate injury. As in that study, 'Autumn Flame' and 'Franksred' (Red Sunset™) were the most ozone-tolerant cultivars evaluated. Townsend and Dochinger (29) determined that red maple seedlings from an Alabama source had the least average foliar injury, while those from Pennsylvania and Minnesota had the highest when exposed to acute ozone concentrations. Visible injury observed in our study was less than what Townsend and Dochinger reported. In another study by Dochinger and Townsend (3), significant differences were reported among 3 red maple progenies in response to both ozone and salinity. These results indicate that while differences in sensitivity to acute exposures of ozone exist among red maple cultivars, visible injury to all cultivars was relatively minor.

Chronic exposure. Visible foliar injury was not observed on red maples exposed to the 3 ozone levels. This indicates that the 4 cultivars evaluated were relatively tolerant to the tested ozone levels in this experiment. As has been reported (10,28), red maples are relatively tolerant to ozone, making them ideal trees for areas with elevated ozone levels.

No differences among the treatments were detected for growth measurements of height, caliper, leaf, shoot, or root dry weight for the cultivars evaluated (data not shown). Jensen (10) observed a slight reduction in height for red maple after 5 months of exposure to 300 ppb, a higher ozone concentration, and a longer duration than in this experiment.

Of the gas exchange parameters measured, only photosynthesis (Pn) at the 4 WEB sampling was affected by ozone treatment. Photosynthesis was 15% higher for the twice-ambient (2X) and 9% higher for the ambient (NF) treatment, 12.8 $\mu mol/m^2/s$ and 12.0 $\mu mol/m^2s$, respectively, than for plants in the sub-ambient (CF) treatment, 10.9 $\mu mol/m^2/s$. The increase in Pn in the 2X treatment is different from that reported in other studies involving David's pine (*Pinus armandi*) (25) and European beech (*Fagus sylvatica*) (21), in which elevated ozone levels caused a reduction in Pn. This increase in Pn could be attributed to reduced ozone levels during the measurement period from the high levels recorded during the previous 3 weeks. Differences among the cultivars for the gas exchange rates were similar to those reported by Sibley et al. (27) and are not reported.

These results indicate that differences in sensitivity to acute ozone exposures exist among red maple cultivars, but visible injury to all cultivars was minor. Although ozone sensitivity is an important criterion for selecting many species, red maple's tolerance to ozone exposures indicates there are more important criteria that need to be evaluated for use in a particular area, such as growth rate, form, fall color, and insect or disease resistance. Red maples that perform well in the southeastern United States—'Autumn Flame', 'Autumn Blaze', 'Franksred' (Red Sunset™), and 'October Glory'—appear to be relatively tolerant to acute ozone exposures, and all cultivars evaluated appear to be relatively tolerant to chronic ozone exposures.

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