

CHAMBER AND FIELD EVALUATIONS OF AIR POLLUTION TOLERANCES OF URBAN TREES¹

by David F. Karnosky

Abstract. Results are presented for a study of the relative air pollution tolerances of 32 urban-tree cultivars as determined by both chamber fumigations and field exposures. Tolerances to ozone and sulfur dioxide, alone and in combination, were determined using short-term, acute doses administered while the plants were inside a plastic fumigation chamber located inside the Cary Arboretum greenhouses. In a follow-up study still underway, representatives of the same cultivars were out-planted at four locations in the greater New York City area. To date, only oxidant-type injury has been observed on trees in the field plots. Cultivars tolerant to all chamber and field exposures were *Acer platanoides* 'Cleveland,' 'Crimson King,' 'Emerald Queen,' 'Jade Glen,' and 'Summershade'; *Acer rubrum* 'Autumn Flame' and 'Red Sunset'; *Acer saccharum* 'Green Mountain' and 'Temple's Upright'; *Fagus sylvatica* 'Rotundifolia'; *Fraxinus pennsylvanica* 'Summit'; and *Ginkgo biloba* 'Fastigate' and 'Sentry.' Cultivars sensitive to ozone as determined by the chamber and field tests and that may serve as bioindicators of the presence of ozone were *Gleditsia triacanthos inermis* 'Imperial' and *Platanus acerifolia* 'Bloodgood.'

Air pollution is one of many abiotic stress factors to which trees growing in or near urban areas are commonly subjected. In the northeastern United States, for example, concentrations of sulfur dioxide (SO₂), oxidants (primarily ozone [O₃]), and suspended particulates frequently exceed federal air quality standards (Goldsmith and Mahoney, 1978).

Two of the most common and most destructive pollutants in urban areas are ozone and sulfur dioxide. These two pollutants probably cause more damage to woody plants than do all other air pollutants combined (Davis and Gerhold, 1976).

While there have been many studies of air pollution tolerances of trees, little information has been gathered on the relative air pollution tolerances of the commonly planted urban-tree cultivars. This paper describes the results of a combination of chamber fumigations and field exposures that have been used to determine the ozone and sulfur dioxide tolerances of 32 commonly planted cultivars of ash, European beech, ginkgo, honeylocust, maple, oak, and planetree. This

study represents one of the first efforts to correlate air pollution tolerances of trees as determined in chamber tests with those determined by field observations on the same plant material.

Plant Materials

The cultivars used in this study were selected on the basis of their being: 1) commonly used in urban plantings in the Northeast, and 2) available from nurserymen in a usable size. An attempt was also made to select cultivars from species with ranges of air pollution tolerance. Thirty to 40 individuals of each cultivar were procured in 1976. An attempt was made to use the largest available plant material that would fit into the air pollution chamber. In this way, the plants were more nearly the size and age at which they would ordinarily be out-planted than has been the case for most air pollution studies of trees.

Chamber Test Methods

The chamber tests consisted of single 7½ hr exposures to either 0.5 ppm ozone, 1.0 ppm sulfur dioxide, or 0.5 ppm ozone plus 1.0 ppm sulfur dioxide. Two replicates of 3 plants per cultivar were given exposure to one of the pollutant regimes. Thus, for each cultivar, a total of 6 plants were exposed to ozone, an additional 6 were exposed to sulfur dioxide, and 6 more were exposed to the combination of the two pollutants. Six plants per cultivar were also exposed to filtered air in the chamber as a control. The plants ranged in height from 3 to 8 ft tall, and all had been grafted at least 1 year prior to the fumigations. The chamber fumigations were done as described by Karnosky (1978). After one week, the plants were scored for injury using the injury index system described by Davis and Coppolino (1974) consisting of the following formula:

$$\text{Injury index} = [(\% \text{ foliage injured}) \times (\text{degree of severity from 1 to 5}) \times (\% \text{ population injured})] / 100.$$

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Field Text Methods

Because most air pollution tolerance testing has been done in chambers, the reliability of extrapolating the results to the field is not well documented. The second phase of this air pollution tolerance testing program involved the planting of trees of the same cultivars used in the chamber tests at various sites in and around New York City. The test sites included the New York Botanical Garden Cary Arboretum (about 70 miles north of New York City), Rutgers — The State University of New Jersey (about 25 miles southwest of New York City), the New York Botanical Garden (in the Bronx), and Rikers Island (in the East River between Queens and the Bronx). The Cary Arboretum site is zone 5 while the other sites are all zone 6. The Rikers Island site is located in the New York City Parks Department's nursery and is on a former landfill. The other three sites are old field sites with established sod cover. The trees were planted in randomized complete block designs consisting of 2 replicates of 2 tree plots. Thus, a total of 4 trees per cultivar were planted at each location. The spacing was 9 × 9 ft. Weed control was done by cultivation at the Rikers Island site and by mowing at the other sites. The trees at Rikers Island were irrigated frequently during each growing season, those at Rutgers and the Cary Arboretum were irrigated only during prolonged drought periods, and those at the New York Botanical Garden were not irrigated. Survival and height growth were scored annually while disease problems and air pollution injury (using the injury index system) were scored monthly during the growing season, as described by Karnosky (1978). The Cary Arboretum and Rikers Island plantings were completed in the spring of 1977 and those at Rutgers and the New York Botanical Garden were done in the spring of 1978.

Air quality information from three locations was used for the field study. The New York State Department of Environmental Conservation's air monitoring data from the Morrisania Health Center (Site No. 7094-02), located about midway between the tree plots at the New York Botanical Garden (2 miles to the northeast) and Rikers Island (3 miles to the southeast) were used to determine

ozone, sulfur dioxide, and nitrogen oxide levels for the two New York City test plots for 1978 and 1979. The same site was also used for 1977 data that were collected by New York City's Department of Environmental Protection. Similar data were obtained for the New York State Department of Environmental Conservation's monitoring station at Poughkeepsie, New York, located about 10 miles west-southwest of the Cary Arboretum test plot. Ozone data for the Rutgers site, provided by Dr. Eileen Brennan and her graduate students, were taken at the New Jersey Department of Environmental Protection's Somerville site within 13 miles of the Rutgers test plot.

Chamber Test Results

The relative tolerances and the injury index score for the 32 cultivars exposed to ozone and sulfur dioxide, alone and in combination, are shown in Table 1. The classifications of tolerant, intermediate, and sensitive were based on three sensitivity groups that had injury index scores as follows: 0 to 10 were considered tolerant, 11 to 30 were intermediate, and above 30 were considered sensitive.

Cultivars showing good tolerance to all three pollutant exposures were all *Acer platanoides* cultivars tested, *Acer rubrum* 'Autumn Flame' and 'Red Sunset,' *Acer saccharum* 'Green Mountain' and 'Temple's Upright,' *Fagus sylvatica* 'Rotundifolia,' *Fraxinus pennsylvanica* 'Summit,' and all *Ginkgo biloba* cultivars tested. Cultivars classed as sensitive to all three pollutant exposures were *Fraxinus americana* 'Autumn Purple' and *Platanus acerifolia* 'Bloodgood.' It should be noted, however, that the 'Bloodgood' showed a remarkable ability for new growth following even nearly total defoliation by the pollutants.

For ozone, 'Autumn Purple,' 'Bloodgood,' all *Gleditsia* cultivars tested, and *Quercus robur* 'Fastigate' were sensitive to chamber exposures. The most common foliar symptom was a randomly distributed upper leaf surface stipple (fleck) that was either black or purple in color. The color tended to fade to tan, brown, or red brown with time (Figure 1). Symptoms were visible within 24 hours of exposure on the sensitive plants and con-

Table 1. Tolerances (and injury index scores) of 32 urban-tree cultivars to ozone (O₃) and sulfur dioxide (SO₂), alone and in combination, as determined by chamber tests and to ambient oxidants (primarily ozone) as determined by field tests. The field exposure ratings are based on 3 years of field observations on the cultivars growing at 4 test sites in the greater New York City area.

Species	Cultivar	Tolerance ¹ (Injury index score) based on			
		Chamber exposures to:			Field exposure to:
		O ₃	SO ₂	O ₃ + SO ₂	oxidants
<i>Acer platanoides</i>	Cleveland	R(0)	R(2)	R(0)	R
	Crimson King	R(0)	R(0)	R(0)	R
	Crimson Sentry	R(0)	I(12)	R(1)	R
	Columnar	R(1)	R(1)	R(1)	R
	Emerald Queen	R(10)	R(0)	R(1)	R
	Jade Glen	R(9)	R(2)	R(2)	R
	Schwedler	I(12)	R(4)	I(12)	R
	Summershade	R(0)	R(0)	R(0)	R
	Autumn Flame	R(0)	R(0)	R(0)	R
<i>Acer rubrum</i>	Bowhall	I(15)	R(1)	S(64)	R
	Red Sunset	R(0)	R(1)	R(0)	R
	Tilford	R(2)	S(54)	R(2)	R
<i>Acer saccharum</i>	Goldspire	R(2)	R(0)	S(68)	R
	Green Mountain	R(0)	R(0)	R(8)	R
	Temple's Upright	R(0)	R(0)	R(0)	R
<i>Fagus sylvatica</i>	Rotundifolia	R(0)	R(0)	R(0)	R
<i>Fraxinus americana</i>	Autumn Purple	S(62)	S(183)	S(39)	R
<i>Fraxinus excelsior</i>	Hessei	I(15)	S(109)	I(20)	R
<i>Fraxinus pennsylvanica</i>	Marshall's Seedless	I(13)	S(112)	S(44)	I
	Summit	R(2)	R(2)	R(3)	R
<i>Ginkgo biloba</i>	Autumn Gold	R(0)	I(14)	R(2)	R
	Fairmont	R(0)	R(1)	I(14)	R
	Fastigiate	R(0)	R(3)	R(1)	R
	Sentry	R(0)	R(0)	R(0)	R
<i>Gleditsia triacanthos inermis</i>	Emerald Lace	S(115)	R(6)	R(8)	R
	Imperial	S(88)	R(0)	R(0)	S
	Majestic	S(80)	S(104)	R(0)	R
	Shademaster	S(76)	R(0)	R(1)	I
	Skyline	S(41)	S(54)	R(1)	R
	Sunburst	S(49)	S(97)	R(1)	I
<i>Platanus acerifolia</i>	Bloodgood	S(137)	S(54)	S(146)	S
<i>Quercus robur</i>	Fastigiate	S(32)	R(0)	R(1)	I

¹S=sensitive, I=intermediate, R=tolerant

tinued to develop for up to one week. Leaf curling and premature leaflet and/or leaf drop was noticed on those plants with the highest injury index scores.

For sulfur dioxide, 'Autumn Purple,' 'Bloodgood,' *Acer rubrum* 'Tilford,' *Fraxinus excelsior* 'Hessei,' *F. pennsylvanica* 'Marshall's Seedless,' and *Gleditsia triacanthos inermis* 'Majestic,' 'Skyline,' and 'Sunburst' were the most sensitive cultivars. The symptoms observed were classic sulfur dioxide symptoms including bifacial, interveinal necrosis. The symptoms were mostly

marginal and towards the leaflet tip for the honeylocust cultivars (Figure 2) but were more randomly distributed for the other species. The color was usually gray-green to light brown within the first 24 hours but bleached quickly to a light tan color by 48 hours after exposure. Severely injured trees also had leaf curling and premature leaf drop.

For the combination of ozone and sulfur dioxide, the most sensitive cultivars were 'Autumn Purple,' 'Bloodgood,' 'Marshall's Seedless,' *Acer rubrum* 'Bowhall' and *A. saccharum* 'Goldspire.' The most

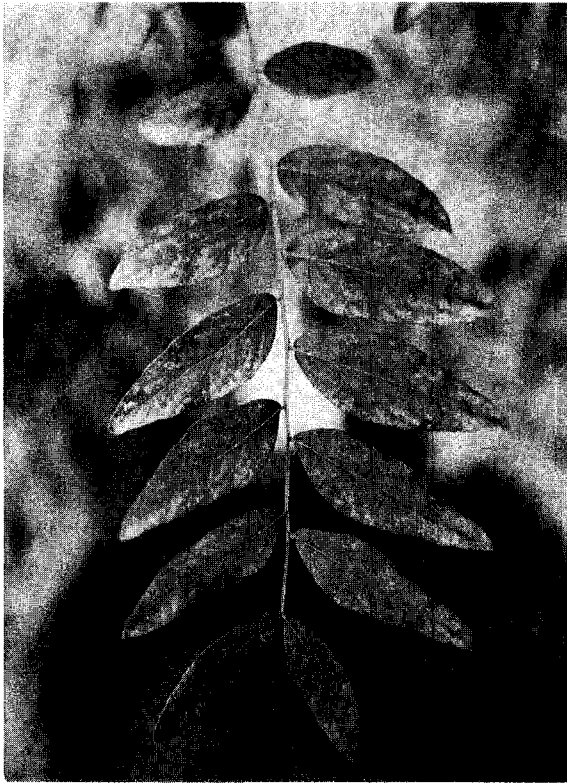


Figure 1. Upper leaf surface necrotic stipple on a *Gleditsia triacanthos inermis* 'Imperial' leaf one week after a 7½ hour fumigation with 0.5 ppm ozone.

common symptoms occurring on trees injured by the pollutant combination were similar to those seen from the single pollutant responses. While sensitive plants occasionally exhibited symptoms of both ozone and sulfur dioxide injury on the same leaves, a more common occurrence was to have symptoms of one pollutant predominate on a given plant.

The sensitive responses of 'Bowhall' and 'Goldspire' were unexpected as they had shown good tolerances to the single pollutant exposures. Also unexpected was the tolerant response of all six *Gleditsia* cultivars. While it is impossible to rule out environmental differences in the chamber or on the stage of leaf development of the plants as possible causes for these inconsistencies, the fact that the ozone, sulfur dioxide, and ozone plus sulfur dioxide fumigations were done randomly and that the experiment was repeated suggests that perhaps the two pollutants reacted

synergistically in the case of 'Bowhall' and 'Goldspire' and antagonistically in the case of the *Gleditsia* cultivars. Further testing of these cultivars utilizing other pollutant combinations will be necessary to verify these responses.

Field Test Results

From monthly observations during the past three growing seasons at the Rikers Island and Cary Arboretum sites, and during the past two growing seasons at the Rutgers and New York Botanical Garden sites, it was evident that the most common type of air pollutant injury symptom present at all four sites was upper leaf surface stipple (flecking) characteristic of ozone (or oxidant) injury. While it is difficult to verify pollutant injury in the field, evidence from this study suggests that ozone (or oxidant) injury was common to a few cultivars at each of the four sites. First, the foliar symptoms in the field were nearly identical to those caused by the chamber fumigations with ozone. Second, only cultivars determined to be ozone-sensitive (in the chamber tests) showed foliar symptoms in the field. None of the ozone-tolerant plants was visibly affected by the field ex-



Figure 2. Marginal and interveinal, bifacial necrosis on *Gleditsia triacanthos inermis* 'Skyline' leaves one week after a 7½ hour fumigation with 1.00 ppm sulfur dioxide.

posures. Third, air monitoring data at or near the four sites revealed the common presence of ozone in the study areas during each of the past three years (see Table 2). Although there are a number of additional oxidants (e.g., peroxyacetyl nitrate, nitrogen oxides) present in plumes from large urban areas, the most common and destructive oxidant is ozone. Although the highest ozone levels recorded in the field (0.18 to 0.19 ppm) were low in comparison to the level used in the chamber study, the levels are within the range of concentrations that will injure sensitive trees when present for a few hours or more (Karnosky, 1976; Wilhour, 1970).

All cultivars tested of *Acer platanoides*, *A. rubrum*, *A. saccharum*, *Fagus sylvatica*, *Fraxinus americana*, *F. excelsior*, and *Ginkgo biloba* were tolerant to ozone in the field. Also tolerant were *Fraxinus pennsylvanica* 'Summit' and *Gleditsia triacanthos inermis* 'Emerald Lace,' 'Majestic,' and 'Skyline.' Cultivars sensitive to ozone in the field were 'Bloodgood' and *Gleditsia triacanthos inermis* 'Imperial.' Upper leaf surface black or purple stipple (fleck) on all but the youngest leaves was commonly seen on these cultivars during the months of July through September. The color faded quickly to tan or shades of brown. Premature leaflet senescence and drop occurred with 'Imperial.' These two cultivars, 'Bloodgood' and 'Imperial,' may prove valuable as bioindicators of the presence of ozone in urban areas. Other cultivars showing occasional oxidant injury were 'Marshall's Seedless,' *Gleditsia triacanthos inermis* 'Shademaster' and 'Sunburst,' and *Quercus robur* 'Fastigiata.' Additional trees in the New York City Parks Department's Nursery on Riker's Island that

commonly showed ozone symptoms during the study were saplings of *Koelreuteria paniculata*, *Platanus acerifolia*, and *Zelkova serrata*.

The foliar necrosis on 'Imperial' and 'Bloodgood' as rated using the injury index system is shown in Table 3. As can be seen in this table, the degree of foliar necrosis varied from site to site and from year to year for these two cultivars. However, with the exception of the low injury index score for 'Imperial' in 1977 at Rikers Island, the injury index scores consistently ranked 'Imperial' and 'Bloodgood' as the most sensitive cultivars in the study. From these data, it is apparent that there was about the same amount of air pollution injury at all four locations. Together the foliar symptom data and air monitoring data support the supposition that the oxidant air pollution problem on trees is not only restricted to urban areas but extends to areas surrounding large cities. The regional character of ozone concentration of the New Jersey-New York metropolitan area has been demonstrated by Cleveland and Graedel (1979) and Spicer *et al.* (1979).

The consistent tolerance of the maple, European ash, European beech, ginkgo, and white ash cultivars and the consistent sensitivity of 'Imperial' and 'Bloodgood' at the four sites representing diverse soil types, in two different growing zones, with different cultural treatments, and having trees with different growth rates (the height growth at the Rikers Island site was almost double that at the other three sites) suggest that the results of these field tests should be reliable for a number of different planting sites in the northeastern United States in growing zones 4 and 5.

Table 2. Summary of the ozone levels recorded near the four test sites. The number of days that the 1-hour ozone concentration exceeded the federal standard of 0.12 ppm are listed along with the highest 1-hour ozone levels recorded during the year growing season at each location.

Monitoring Station ¹	1977		1978		1979	
	No. Days 0.12 ppm	Highest Conc. (ppm)	No. Days 0.12 ppm	Highest Conc. (ppm)	No. Days 0.12 ppm	Highest Conc. (ppm)
New York City	5	0.18	7	0.19	0	0.12
Poughkeepsie	—	—	4	0.16	0	0.10
New Brunswick	—	—	2	0.13	4	0.16

¹The New York City monitoring site was within 3 miles of both the Rikers Island and New York Botanical Garden tree plots and the Poughkeepsie monitoring site was within 10 miles of the Cary Arboretum tree plot. The New Brunswick ozone data was taken from a site within 13 miles of the Rutgers tree plot.

Table 3. The injury index scores for ozone symptoms on the *Gleditsia triacanthos inermis* 'Imperial' and the *Platanus acerifolia* 'Bloodgood' at each site and for each year are shown below. Although there was considerable variation in the numerical scores, these two cultivars were consistently the most ozone sensitive at all four sites and for all three years.

Cultivar	Location	Injury index score ¹			
		1977	1978	1979	Average
'Imperial'	Rikers Island	19	182	152	118
	New York Botanical Garden	—	215	52	134
	Cary Arboretum	180	175	160	172
	Rutgers	—	66	89	89
		Cultivar Average:			131
'Bloodgood'	Rikers Island	195	132	75	134
	New York Botanical Garden	—	65	40	53
	Cary Arboretum	90	53	100	81
	Rutgers	—	114	120	117
		Cultivar Average:			98

¹Based on the four trees of each cultivar at each location and using the maximum injury scores for that growing season.

Discussion

This study has demonstrated that there is a wide range of variation in foliar response to ozone and sulfur dioxide in urban-tree cultivars that are commonly planted in the northeastern United States. Although the 'Bloodgood' London planetree was found to be sensitive to ozone and sulfur dioxide in this study, the rapid growth rate and indeterminate growth habit of 'Bloodgood' enable it to withstand a substantial amount of foliar injury. However, repeated pollutant injury during a growing season would probably reduce growth and may also predispose the tree to secondary insect and/or disease pests.

This study represented one of the first attempts to compare chamber and field evaluations of air pollution tolerances on the same trees. While chamber and field evaluations of ozone tolerance were generally in agreement (Table 1), there were several important changes in the relative tolerance rankings. For example, the 'Autumn Purple' white ash and the 'Emerald Lace,' 'Majestic,' and 'Skyline' honeylocusts were sensitive to the chamber ozone tests but were tolerant to the ambient ozone exposures in the field. Because the chamber exposures were done at a high concentration for a short period of time and since the plants were growing under nearly optimum condi-

tions of nutrients, water, light, and temperature in the greenhouse, I believe the field ozone tolerance rankings are more realistic than the chamber ozone tolerance rankings developed in this study. The results of this chamber and field comparison suggest that a reexamination of ozone sensitivity lists developed from chamber observations is needed.

Acknowledgment

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ABSTRACTS

Fucello, Jean & J.S. Brock. 1980. **Two municipalities develop urban forest plans.** Michigan Municipal Review 53(3): 58-59.

In recent years, many communities have become increasingly aware of the value of their urban forests. For many small communities, such as Saline (pop. approx. 7,000) and Zeeland (pop. approx. 5,200), the large number of mature shade trees lining streets and adorning parks and other public and private lawns add materially to their attractiveness and charm. The loss of these trees, or even substantial quantities of them, would produce considerable monetary, environmental, and aesthetic effects. The city, as the largest single owner of trees, is perforce the logical leader in any effort toward good urban forestry management. The urban forestry programs in Saline and in Zeeland, Michigan are described and discussed.

Svihra, Pavel & J.K. Clark. 1980. **The courtship of the elm bark beetle.** California Agriculture 34(4): 7-9.

The smaller European elm bark beetle is responsible for most spread of the devastating Dutch elm disease. Little is known about why the smaller European elm bark beetle feeds in elm twig crotches. Entomologists believe that such feeding is not mandatory and that, when it occurs, the beetle uses the feeding cavity in the crotch as protection, waiting for favorable weather conditions before selecting a breeding site. We observed aggregation and courtship behavior in living elm tissue, during the beetle's feeding in the crotches of small twigs. In the laboratory, we observed and photographed courtship by both sexes in the twig crotches, which resulted in successful copulation. The text and photographs here are based on 100 samples of each of two sequences: courtship behavior of the male when the female was in the feeding cavity, and courtship behavior of the female when the male was in the feeding cavity.