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Ozone Sensitivity of Selected Southeastern Landscape Plants[1]

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Abstract

Twenty-six species and/or cultivars commonly used in landscapes of the southeastern United States were exposed to three ozone (O_3) levels for 3-week periods during spring and summer 1994. Thirteen species or cultivars exhibited visible foliar injury at the highest rate, 2.5× ambient, and two cultivars exhibited foliar injury with ambient O_3 concentrations. The most sensitive were two cultivars of buddleia or butterfly bush (*Buddleia davidii* Franch. 'Black Knight' and 'Royal Red'), with visible injury under ambient and 2.5× ambient O_3 levels, and 'White Star' zinnia (*Zinnia angustifolia* HBK 'White Star') with visible injury observed under 2.5× ambient O_3 levels. Seven other cultivars of buddleia and three cultivars of red maple (*Acer rubrum* L. 'Autumn Flame', 'October Glory', and 'Franksred' (Red Sunset™)) exhibited minor foliar injury under 2.5× ambient O_3 levels. Visible injury was not present on flowering dogwood (*Cornus florida* L. 'Stokes Pink'), hollies (*Ilex crenata* Thunb. 'Green Luster', *I. cornuta* Lindl. & Paxt. 'Carissa', *I.* x *attenuata* Ashe 'Fosteri #2'), cultivars of crapemyrtle (*Lagerstroemia indica* L. 'Byers Wonderful White' and 'Carolina Beauty'), glossy abelia (*Abelia* x *grandiflora* (Andre) Rehd.), southern waxmyrtle (*Myrica cerifera* L.), sawtooth oak (*Quercus acutissima* Carruth), begonia (*Begonia semperflorens-cultorum* Hort. 'Pizzazz Red'), petunia (*Petunia* x *hybrida* Hort. Vilm.-Andr. 'Celebrity Red'), salvia (*Salvia splendens* Sello. 'Hotline'), or gomphrena (*Gomphrena globosa* L. 'Strawberry Fields').

Index words: tropospheric ozone, open-top chambers, visible foliar injury, air pollutant.

Species used in this study: Red maple (*Acer rubrum* L.'Autumn Flame', 'Franksred', and 'October Glory'); sawtooth oak (*Quercus acutissima* Carruth); flowering dogwood (*Cornus florida* L. 'Stokes Pink'); crapemyrtle (*Lagerstroemia indica* L. 'Byers Wonderful White' and 'Carolina Beauty'); Japanese holly (*Ilex crenata* Thunb. 'Green Luster'); Chinese holly (*Ilex cornuta* Lindl. & Paxt. 'Carissa'); Foster holly (*Ilex* x *attenuata* Ashe 'Fosteri #2'); glossy abelia (*Abelia* x *grandiflora* (Andre) Rehd.); southern waxmyrtle (*Myrica cerifera* L.); butterfly bush (*Buddleia davidii* Franch. 'Black Knight', 'Charming Summer', 'Empire Blue', 'Opera', 'Pink Delight', and 'Royal Red', *B. davidii nanhoensis* (Chitt.) Rehd. 'Nanho Blue', *B. fallowiana* Balf. F. & W.W. Sm. 'Lochinch', and *B.* x *weyeriana* L. 'Sungold'); begonia (*Begonia semperflorens-cultorum* Hort. 'Pizzazz Red'); gomphrena (*Gomphrena globosa* L. 'Strawberry Fields'); petunia (*Petunia* x *hybrida* Hort. Vilm.-Andr. 'Celebrity Red'); salvia (*Salvia splendens* Sello. 'Hotline'); and zinnia (*Zinnia angustifolia* HBK 'White Star').

Significance to the Nursery Industry

Visual appearance is a primary attribute professional and nonprofessional consumers evaluate in selection and use of landscape plants. Any condition, including exposure to tropospheric O_3, that adversely alters visual appearance is likely to reduce marketability of a plant. Foliar injury did not occur or was minor for most species exposed to ambient or elevated O_3 levels, demonstrating tolerance to elevated O_3 levels of some landscape plants commonly grown in the southeastern United States. However, of the nine cultivars of buddleia evaluated, 'Black Knight', and 'Royal Red' exhibited minor foliar injury under ambient O_3 levels, and severe foliar injury under elevated O_3 levels. 'White Star' zinnia also was injured severely under elevated O_3 levels. Injury was severe enough to limit selection and use in areas known to be affected by elevated O_3 levels. Injury observed on the other seven cultivars of buddleia and cultivars of red maple was to < 9% of the leaves and should not preclude their use in areas exposed to elevated O_3 levels.

Introduction

Since being identified as a phytotoxic, gaseous air pollutant in the 1950s (15), ozone (O_3) has become progressively the major air pollutant across the United States. Although tropospheric O_3 is normally associated with urban areas, it is readily transported long distances to non-urban areas (24). In unpolluted areas, O_3 concentrations range between 20 and 45 parts per billion (ppb), while in more industrialized regions, O_3 concentrations as high as 300 ppb have been reported (21). Several mathematical models predict that O_3 concentrations will continue to increase between 0.3% and 1.0% per year for the next 50 years (17, 22). The major effects of O_3 on terrestrial vegetation include visible injury and reductions in growth, productivity, and plant quality (14, 18).

Visible injury from O_3 has been reported on a wide variety of landscape plants in the northeastern United States including azaleas (*Rhododendron* L. spp.), sweet mock-orange (*Philadelphus coronarius* L.), tea viburnum (*Viburnum setigerum* Hance), spreading cotoneaster (*Cotoneaster divaricata* Rehd. & E.H. Wils.), and multiflora rose (*Rosa multiflora* Thunb.) (1, 2). Differences in sensitivity among cultivars to O_3 has been reported for plants such as azaleas (8), trembling aspen (*Populus tremuloides* Michx.) (10), and eastern white pine (*Pinus strobus* L.) (7).

Chronic O_3 effects are caused by exposure to frequent, relatively low hourly concentrations, with periodic, random, intermittent peaks of relatively high hourly concentrations on one or more days, as opposed to acute O_3 effects caused by exposure to high hourly concentrations for short durations (13). Chronic injury develops slowly, over several days,

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Table 1. Plants evaluated for visible injury following exposure to three O_3 regimes.

Plant types	Cultivars	Type[z]	Pot size in liters
Acer rubrum L.	'Autumn Flame'	TC	13.3
	'Franksred' (Red Sunset™)	TC	13.3
	'October Glory'	TC	13.3
Quercus acutissima Carruth	—	S	13.3
Cornus florida L.	'Stokes Pink'	L	13.3
Lagerstroemia indica L.	'Byers Wonderful White'	L	13.3
	'Carolina Beauty'	L	13.3
Ilex crenata Thunb.	'Green Luster'	L	2.7
Ilex cornuta Lindl. & Paxt.	'Carissa'	L	2.7
Ilex x *attenuata* Ashe	'Fosteri #2'	L	2.7
Abelia x *grandiflora* (Andre) Rehd.	—	L	2.7
Myrica cerifera L.	—	S	2.7
Buddleia davidii Franch.	'Black Knight'	L	2.7
	'Charming Summer'	L	2.7
	'Empire Blue'	L	2.7
	'Opera'	L	2.7
	'Pink Delight'	L	2.7
	'Royal Red'	L	2.7
B. davidii nanhoensis (Chitt.)Rehd.	'Nanho Blue'	L	2.7
B. fallowiana Balf. f. &W.W. Sm.	'Lochinch'	L	2.7
B. x *weyeriana*	'Sungold'	L	2.7
Begonia semperflorens-cultorum Hort.	'Pizzazz Red'	P	2.7
Gomphrena globosa L.	'Strawberry Fields'	P	2.7
Petunia x *hybrida* Hort. Vilm.-Andr.	'Celebrity Red'	P	2.7
Salvia splendens Sello.	'Hotline'	P	2.7
Zinnia angustifolia HBK	'White Star'	P	2.7

[z]Type indicates how the plant was produced initially: TC = tissue cultured; S = seedling; L = rooted liner; P = annual plug.

and is expressed on broadleaved plants as flecking, chlorosis, stippling, premature senescence, and necrosis (11). While visible injury may be tolerable in much of production agriculture, even slight visible injury may make landscape plants undesirable to consumers.

Most of the literature reporting O_3 injury has been with plants grown in the northeastern United States. However, information is needed on O_3 sensitivity of landscape plants grown in southern hardiness zones. This experiment was therefore designed to determine symptoms of chronic O_3 exposure and sensitivity of several species and cultivars of landscape plants grown commonly in the southeastern United States.

Materials and Methods

Plant culture. Uniform liners, seedlings, or annual plugs of 26 species or cultivars of plants grown commonly in landscapes of the southeastern United States were transplanted into 2.7 liter (#1) or 13.3 liter (#4) pots (depending on plant size) in a 7:1 (by vol) pine bark and sand medium in March 1994 (Table 1). The medium was amended per m^3 (yd^3) with 4.7 kg (8 lb) 22N–2.6P–11.6K (22–6–14) Polyon (Pursell Industries, Sylacauga, AL), 0.9 kg (1.5 lb.) Micromax (The Scotts Company, Marysville, OH), and 3.0 kg (5 lb) dolomitic limestone. Liners and seedlings were maintained on gravel container beds, and annuals were maintained in a double layer polyhouse with ventilation and heat setpoints of 25.6C (78F) and 21C (70F), respectively. Plants were watered as needed in both locations. Three plants of each species or cultivar were placed in a completely randomized design within an O_3 chamber in May 1994 and exposed to various O_3 treatments for 3 weeks. Due to a limited number of chambers, the experiment was replicated over time (June, July, and August 1994) with a new group of plants from the original potting. Each time period represented a separate block. Plants were watered by hand as needed to avoid drought stress while in the chambers.

Ozone treatments. Ozone treatments consisted of sub-ambient (CF) air, in which air was filtered through activated carbon to reduce O_3 to about 50% of ambient levels; nonfiltered ambient (NF) air (Auburn, AL, classified as a rural setting); and air injected with O_3 at 2.5× ambient level (2.5×). The latter treatment represents O_3 concentrations similar to those reported in urban areas of the southeastern U.S. such as Birmingham, AL or Atlanta, GA (12). These treatments were injected into three, 4.6 m wide × 3.5 m tall (15.1 ft × 11.5 ft) open-top fumigation chambers.

Table 2. Ozone 12-hour treatment means[z], SUM0[y], SUM06[x], SUM12[w], and the number of hours above 120 ppb.

	Treatment		
	Sub-ambient (CF)	Ambient (NF)	2.5× ambient (2.5×)
12-hr mean (ppb)	20.2 ± 3	35.3 ± 5	83.8 ± 8
SUM0 (ppm-h)	19.9 ± 2	29.7 ± 3	55.3 ± 8
SUM06 (ppm-h)	0	1.8 ± 1	37.9 ± 11
SUM12 (ppm-h)	0	0	10.9 ± 7
No. hr > 120 ppb	0	0	40.3 ± 15

[z]12-hr (0900–2100) ozone treatment means.

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

[x]SUM06 = 24-hr sum of all hourly ozone concentrations ≥ 60 ppb.

[w]SUM12 = 24-hr sum of all hourly ozone concentrations ≥ 120 ppb.

Ozone was generated by passing pure oxygen through a high intensity electrical discharge source (Griffen, Inc., Lodi, NY) and added to the chambers 12-hr per day (0900–2100), 7 days per week. Fans did not operate from 2300–0600 to permit dew formation within the chambers. Within each chamber, O_3 concentrations were monitored for 2 min every ½ hr using an U.S. Environmental Protection Agency (EPA) approved monitor (Thermo Environ. Instr., Hopkinton, MA) with continuous adjustments. An air exchange rate of two exchanges per min facilitated mixing and cooling within a chamber.

To characterize O_3 exposures within each treatment, O_3 12-hr (0900–2100) treatment means, SUM0 values (24-hr sum of hourly average O_3 concentrations), SUM06 values (24-hr sum of hourly averages ≥ 60 ppb), SUM12 values (24-h sum of hourly averages ≥ 120 ppb), and the number of hours ≥ 120 ppb, the National Ambient Air Quality Standard for O_3 (24), were calculated (Table 2).

Foliar injury. Plants were evaluated at the end of 3-week exposure periods in their respective chambers for visible injury by estimating the percentage of leaves injured (PLI). Leaves with visible foliar injury were rated further for the percentage of leaf area injured using the Horsfall-Barratt rating scale for foliar injury (9). This rating scale ranges from 1 to 12 with 1 indicating 0% of the leaf area exhibiting foliar injury and 12 indicating 100% of the leaf area exhibiting foliar injury. Plants were re-evaluated 1 and 2 weeks after removal from the chambers for further symptom development.

Statistical analysis. A split-plot design with four blocks replicated over time containing three plants/cultivar/O_3 treatment was used to test for O_3 treatment effects. All data were arc-sine transformed prior to performing analysis of variance (ANOVA); retransformed data are presented. Cultivars within a taxa were compared using Duncan's multiple range test at $P \leq 0.05$.

Results and Discussion

No plants in the sub-ambient (CF) treatment exhibited symptoms of foliar injury during the study, and only two cultivars of buddleia, 'Black Knight' and 'Royal Red' developed visible injury symptoms in the ambient (NF) O_3 treatment. In the 2.5× ambient (2.5×) O_3 treatment, visible injury was detected on all nine cultivars of buddleia, all three cultivars of red maple, and zinnia. No visible injury was apparent on any of the remaining species or cultivars. Visible foliar injury symptoms varied among species but were uniform among the cultivars of a species. On all affected plants of buddleia and zinnia, injury was first observed on the oldest foliage, and symptom expression decreased with decreasing leaf age. Injury was first noted on the most recently expanded leaves of the red maple cultivars, indicating the youngest, expanding leaves and the oldest foliage, produced prior to O_3 exposure, were more tolerant to elevated O_3 concentrations.

Visible injury on buddleia consisted of dark maroon or brown stippling and bronzing on the upper leaf surface. Some of the oldest leaves also developed a general chlorosis as the severity of injured increased. The most severely injured leaves tended to senesce within 1 week of removal from the chambers with new leaf buds breaking shortly thereafter to replace lost foliage. These symptoms were similar among the cultivars of buddleia and within both the NF and 2.5× treatments with only the severity of injury differing. Differences in sensitivity among cultivars of buddleia occurred as evidenced by the significant O_3 × cultivar interaction for percentage of the leaves injured (PLI) and the Horsfall-Barratt (H-B) rating. PLI increased linearly with increasing O_3 concentrations for all cultivars except 'Empire Blue', 'Opera', 'Pink Delight', and 'Sungold' (Table 3). In the NF O_3 treatment only two cultivars, 'Black Knight' and 'Royal Red', exhibited visible injury with PLI values of 7.2% and 6.8%, respectively. In the 2.5× O_3 treatment all cultivars were injured visibly but severity varied among cultivars. 'Royal Red' was the most severely injured cultivar with a PLI of 57.1% followed by 'Black Knight' with a PLI of 35.0%; injury was present on all but the youngest leaves. PLI values for the remaining cultivars were < 10%.

Ratings of visibly injured leaves, measured using the Horsfall-Barratt (H-B) rating scale, increased linearly with increasing O_3 concentrations for all cultivars except 'Empire Blue', 'Opera', and 'Sungold' (Table 4). In the NF O_3 treatment, 'Black Knight' and 'Royal Red' had H-B ratings of 3.4 and 3.2 respectively, indicating between 3% and 6% of the area of injured leaves exhibited visible symptoms. In the 2.5× O_3 treatment, 'Royal Red' was the most severely injured cultivar with a H-B rating of 6.7 which corresponds to 50% to 75% of the area of injured leaves exhibiting visible symptoms. 'Black Knight' had a H-B rating of 5.9 corresponding to leaf area injury of 25% to 50%. All other cultivars had ratings ≤ 2.3 indicating 1% to 3% of the area of injured leaves exhibited symptoms. 'Royal Red' and 'Black

Table 3. Percentage of leaves injured (PLI) on cultivars of buddleia exposed to three levels of ozone[z].

	Cultivar								
Treatment	Black Knight	Charming Summer	Empire Blue	Lochinch	Nanho Blue	Opera	Pink Delight	Royal Red	Sungold
Sub-ambient	0.0a[y]	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
Ambient	7.2a	0.0b	0.0b	0.0b	0.0b	0.0b	0.0b	6.8a	0.0b
2.5× ambient	35.0b	5.4c	3.9c	8.3c	4.2c	2.5c	3.6c	57.1a	4.4c
Significance[x]	L***	L*	NS	L*	L*	NS	NS	L***	NS

[z]Ozone treatment × cultivar interaction significant at $p \leq 0.001$. Data were arc-sin transformed before analysis. Retransformed means are presented.

[y]Mean separation within rows by Duncan's multiple range test, $p \leq 0.05$.

[x]NS, L: nonsignificant or linear response significant at 0.05 (*) or 0.001 (***).

Table 4. Horsfall-Barratt (H-B) rating of foliar injury for cultivars of buddleia exposed to three levels of ozone.[z]

Treatment	Cultivar								
	Black Knight	Charming Summer	Empire Blue	Lochinch	Nanho Blue	Opera	Pink Delight	Royal Red	Sungold
Sub-ambient	1.0a[y]	1.0a	1.0a	1.0a	1.0a	1.0a	1.0a	1.0a	1.0a
Ambient	3.4a	1.0b	1.0b	1.0b	1.0b	1.0b	1.0b	3.2a	1.0b
2.5× ambient	5.9a	2.3b	1.7b	2.3b	2.1b	1.5b	1.9b	6.7a	1.9b
Significance[x]	L***	L***	NS	L**	L**	NS	L*	L***	NS

[z]Ozone treatment × cultivar interaction significant ($p \leq 0.001$). H-B rating data were arc-sin transformed before analysis. Retransformed mean values are presented. The H-B rating scale is: 1 = 0, 2 = 1–3, 3 = 3–6, 4 = 6–12, 5 = 12–25, 6 = 25–50, 7 = 50–75, 8 = 75–87, 9 = 87–94, 10 = 94–97, 11 = 97–99, 12 = 100% of the leaf area is injured.

[y]Mean separation within rows by Duncan's multiple range test, $p \leq 0.05$.

[x]NS, L: nonsignificant or linear response significant at $p \leq 0.05$ (*), 0.01 (**) or 0.001 (***).

Knight' had the highest PLI and H-B rating, while 'Opera' had the lowest PLI and H-B rating.

Although flowering dates were not recorded, the authors observed that flowering was delayed by 3 to 4 days in the 2.5× treatment for cultivars of buddleia. We also observed that spider mites appeared to prefer plants exposed to the highest O_3 treatment. Spider mite damage consisted of small white to light green areas on the upper surface of the leaf while on the underside of the leaf webbing, frass, and individual insects were visible with a hand lens. This insect preference for leaves exposed to O_3 is similar to that reported by Endress and Post (5) with soybean (*Glycine max* (L.) Merrill) infested with Mexican bean beetle (*Epilachna varivestis* Mulsant). The most severely injured leaves were observed senescencing within 1 week of removal from the 2.5× treatment, similar to that reported for several tree species including beech (*Fagus sylvatica* L.) (16) and black cherry (*P. serotina* Ehrh.) (3). The amount of leaf senescence did not appear cultivar-dependent.

Minor visible injury, characterized as a light stippling and slight bronzing on the upper leaf surface, occurred on all three cultivars of red maple, but only in the 2.5× treatment (Table 5). The O_3 × cultivar interaction was nonsignificant for the PLI and H-B ratings. Both ratings increased linearly as O_3 concentration increased, with a PLI of 4.1% and H-B rating of 1.6 (1% to 3% of the area of injured leaves exhibiting symptoms) in the 2.5× treatment. Injury was confined to recently expanded leaves, similar to results reported by Dochinger and Townsend (4). Variable response to O_3 for leaves of red maple of different ages on the same tree has been reported in other studies as well (3, 7, 20, 29). Injury detected was slight and concurs with previous studies indicating red maples are relatively tolerant to elevated O_3 levels (3).

Table 5. Percentage of the leaves injured (PLI) and Horsfall-Barratt (H-B) ratings for foliar injury on 'Autumn Flame', 'Franksred' (Red Sunset™), and 'October Glory' red maple exposed to three levels of ozone[z].

Treatment	PLI	H-B rating[y]
Sub-ambient	0.0	1.0
Ambient	0.0	1.0
2.5× ambient	4.1	1.6
Significance[x]	L***	L***

[z]Ozone × cultivar interaction is nonsignificant and values are means across cultivars.

[y]PLI and H-B rating data were transformed using an arc-sin transformation before statistical analysis. Retransformed mean values are presented. The rating scale is: 1 = 0% and 2 = 1%–3% of the leaf area is injured.

[x]L: linear response significant at $p \leq 0.001$.

Visible injury on 'White Star' zinnia was characterized as a uniform light tan stippling on the upper leaf surface. This injury was detected on the lower half of the plant with fewer stipples on portions of leaves shaded by other leaves. The PLI of 40% and H-B rating of 5.9 (25% to 50% of the leaf area injured) were relatively high. Injury severity was similar to that on the most severely injured cultivars of buddleia. *Zinnia elegans* Jacq. has been listed as being tolerant to O_3 (23) but this cultivar of *Z. angustifolia* appeared to be quite sensitive.

There are similarities and differences when comparing results of this study with ones published previously. Similar to previous studies, flowering dogwood and holly were relatively tolerant to O_3 (1). While not tested in previous studies crapemyrtle, glossy abelia, southern waxmyrtle, sawtooth oak, salvia, and gomphrena were also relatively tolerant to O_3. Butterfly bush was not tested in previous studies, and cultivars exhibited differences in sensitivity to O_3. Differences in sensitivities among cultivars of petunia and begonia have been reported in other studies with petunia 'Canadian All Double Mix', 'Festival', 'Roulette', and 'Red Magic' and begonia 'Linda' and 'White Tausendschon' being sensitive (6, 19) but the cultivars we evaluated were tolerant.

Results herein provide needed information on sensitivity, including symptoms of O_3 injury, of selected landscape plants grown in southern hardiness zones. Species or cultivars evaluated in this study were identified as sensitive and tolerant. Of the 26 species or cultivars, 13 exhibited visible injury symptoms after a 3-week exposure to elevated O_3 concentrations, indicating both inter- and intraspecific differences in sensitivity to O_3. While all nine cultivars of buddleia exhibited visible injury, the severity of injury differed; most cultivars were tolerant except for 'Black Knight' and 'Royal Red'. 'White Star' zinnia also showed extensive visible injury to O_3. Visible injury observed on the other cultivars of buddleia and red maple was minor and should not preclude their use in areas exposed to elevated O_3 levels.

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