at low sulphur dioxide concentrations. Nature 224:1229-1231.
34. Treshow, M., and M. R. Pack. 1970. Fluoride. *In*: Recognition of Air Pollution Injury to Vegetation: A Pictorial Atlas. Air Pollut. Control Assoc. Pittsburgh, Penn. D1-D6.
35. Weinstein, L. H. 1977. Fluoride and plant life. J. Occupational Medicine 19(1):49-78.
36. Wilson, L. G., R. A. Bressan, and P. Filner. 1978. Light-dependent emission of hydrogen sulfide from plants. Plant Physiol. 61:184-189.
37. Winner, W. E., and H. A. Mooney. 1980. Ecology of SO_2 resistance: I. Effects of fumigations on gas exchange of deciduous and evergreen shrubs. Oecologia 44:290-295.
38. Ziegler, I. 1973. Effect of sulphite on phosphoenolpyruvate carboxylase and malate formation in extracts of *Zea mays*. Phytochemistry 12:1027-1030.
39. ———. The effect of SO_3 on the activity of ribulose-I, 5-diphosphate carboxylase in isolated spinach chloroplasts. Planta 103:155-163.
40. Zimmerman, P. W., and A. E. Hitchcock. 1956. Susceptibility of plants to hydrofluoric acid and sulfur dioxide gases. Contrib. Boyce Thompson Inst. 18:263-279.

Proc. Fla. State Hort. Soc. 94:121-123. 1981.

SYMPTOMOLOGY AND RELATIVE SUSCEPTIBILITY OF VARIOUS ORNAMENTAL PLANTS TO ACUTE AIRBORNE SULFUR DIOXIDE EXPOSURE[1,2]

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Abstract. **The effect of airborne sulfur dioxide on ornamental plants was examined by comparative greenhouse fumigation of various foliage plants, landscape ornamentals, and flowering ornamentals at 0, 0.5, 1.0, and 2.0 ppm SO_2. Selected SO_2 levels allowed placement of plants into very low, low, intermediate, high and very high susceptibility categories based on foliar injury. Foliar symptoms included marginal and interveinal necrosis and enhanced chlorosis. Flowers generally were not affected by SO_2 exposure, but occasionally were the most susceptible organ.**

Fossil fuel combustion is the major source of sulfur dioxide (SO_2) air pollution and electrical generation accounts for approximately 73% of this country's SO_2 emissions (7). Since 90% of global fossil fuels is coal, conversion of electrical plants from oil- to coal-burning facilities is inevitable and has begun due to depletion of world oil reserves. This conversion will contribute increasing amounts of SO_2 to the atmosphere. As populations increase, particularly in Florida, electrical facilities will increase in number and add to a worsening atmospheric condition.

The impact on ornamental horticulture may be occassional, but severe. Economic loss to horticultural crops due to SO_2 pollution will be increasingly significant. Serious damage to plants at the nursery makes them unmarketable products, and in the urban landscape causes aesthetic and economic loss.

Susceptibility to SO_2-induced injury varies within and among plant species (1-6, 8, 9, 11). Information on species commonly grown in Florida with regard to their susceptibility-tolerance levels will facilitate the diagnosis of SO_2-induced injuries and aid in the establishment of cultural practices to avoid potential hazards near SO_2 emission areas. This report describes susceptibility of various ornamental plants to airborne SO_2 as determined by comparative fumigation techniques.

Materials and Methods

Forty-three types of plants were evaluated for susceptibility to acute SO_2 exposure and were categorized as landscape, foliage or flowering plants (Table 1). All landscape and foliage plants were fumigated soon after acquisition from local nurseries. Flowering plants, however, were obtained as seedlings or grown from seed to maturity at the AREC-Bradenton.

Fumigations were conducted over a period of several months from February through May, 1981. Exposure to SO_2 was carried out in 7 fumigation greenhouses as previously described by Woltz and Waters (10). Five flowering plants or 4 foliage or landscape plants of each type were placed randomly in each greenhouse one day prior to exposure. Two houses received 0.5 ppm SO_2 for 8 hrs, 2 houses received 1.0 ppm SO_2 for 4 hrs, 2 houses received 2.0 ppm SO_2 for 2 hrs, and 1 house was a non-fumigated control. A cylinder of compressed SO_2 (1.5% in air) was used as the fumigant source and was metered into the houses via a fan which drew ambient air through evaporative cooling pads. Greenhouse atmosphere (24 m^3) was exchanged once every 2 minutes. SO_2 concentrations were monitored by a Thermo-Electron Model 43 SO_2 Analyzer calibrated with permeation tubes in a Metronics Dyna-calibrator. Fumigations began at 9 AM and were conducted on sunny days.

Relative humidity and temperature varied with outside conditions over several months and ranged from 25-85% and 10-38°C, respectively. Generally, light intensity in the greenhouses was 30% of full sunlight.

One to 3 days after fumigation plants were rated visually for percent leaf area necrosis and symptomology of SO_2 injury to each species was recorded. Plant were placed in 1 of 5 categories for susceptibility to acute SO_2 exposure. These categories were very high, high, medium, low and very low susceptibility to SO_2-induced damage. Categories were chosen based on relative comparison of a species' injury or lack of injury to others tested, and to geranium, a plant of known susceptibility to SO_2. A photographic library was compiled to facilitate accurate symptomological descriptions.

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Table 1. Effects of airborne sulfur dioxide on selected foliage, flowering, and landscape plants.

Species	Common name	Sulfur dioxide susceptibility[z]	Symptoms associated with injury
FOLIAGE PLANTS			
Aphelandra squarrosa 'Dania'	Zebra plant	L[y]	Marginal and interveinal necrosis. Apical and basal leaves most susceptible. Scorched areas dark brown.
Asparagus densiflorus 'Sprengeri'	Asparagus fern	M[y]	White tip burn, damaged area extending basipetally with exposure. Extreme foliar necrosis followed by defoliation.
Chlorophytum comosum 'Variegatum'	Spider plant	L[y]	Brown tip burn, damaged area extending basipetally with exposure.
Dieffenbachia 'Perfection Compacta'	Dumbcane	VL[y]	No damage.
Neoregalia perfecta 'Tricolor'	Bromeliad	VL	No damage.
Philodendron 'Emerald King'	Emerald King philodendron	VL	No damage.
Philodendron 'Red Princess'	Red Princess philodendron	VL	No damage.
Scindapsus aureus 'Marble Queen'	Pothos	VL	No damage.
Selloum philodendron	Selloum philodendron	VL	No damage.
Vaccinium ovatum	Leatherleaf fern	VL	Orange tip and marginal scorch.
FLOWERING PLANTS			
Ageratum Houstonianum	Flossflower	VH	Gray necrosis, evenly or unevenly interveinal and marginal. Fully mature leaves most susceptible.
Antirrhinum majus	Snapdragon	M	Gray-green marginal and interveinal scorch which becomes white.
Begonia semperflorenscultorum	Begonia	VH	Water soaked areas on margins and between veins become gray-brown and then white to transparent. Tissue then resembles onion skin and will tatter. Flower margins also become necrotic.
Callistephus chinensis	Aster	H	Tan necrosis following leaf margins and between veins.
Chrysanthemum morifolium	Chrysanthemum	H	Tan-orange necrosis originating on leaf margins and becoming interveinal.
Euphorbia pulcherrima	Poinsettia	L	White interveinal necrosis. Green foliage most susceptible.
Impatiens wallerana	Impatiens	L	White necrosis, interveinal and marginal.
Pelargonium hortorum	Geranium	H	Lower acute exposures cause marginal foliage scorch. If flowers present, sepals display tip burn even if foliage shows no symptoms. Higher acute exposures cause interveinal and marginal foliar scorch.
Petunia x *hybrida*	Petunia	L, M, H	Susceptibility dependent on cultivar. Necrosis interveinal, white.
Tagetes spp.	Marigold	L, M, H	Susceptibility dependent on cultivar. Necrosis of foliage may be marginal and/or interveinal. Some cultivars selectively scorched at extra-floral nectaries on leaf margins. Sepals very sensitive to pinpoint scorch and tip burn.
Verbena hortensis	Verbena	VH	Edge and interveinal scorch. Beige to white.
Vinca rosea	Periwinkle	VL	No damage.
Viola tricolor	Pansy	VL	No damage.
Zinnia elegans	Zinnia	VH	Interveinal and marginal necrosis. Beige to white.
LANDSCAPE PLANTS			
Araucaria heterophylla	Norfolk Island pine	VL	No damage.
Araucaria heterophylla Casuarina	Australian pine	VL	No damage.
Azalea cardinalis 'Pink Ruffles'	Azalea	H	Butterscotch colored foliar scorch. Tip and edge burn progresses interveinally. Leaves most severely affected are above and surrounding flowers and at branch terminals. Defoliation follows heavy foliar injury. Scorch not always bifacial. Most damage on abaxial surface.
Beaucarina recurvata	Ponytail palm	VL	No damage.
Brassaia actinophylla	Schefflera	VL	No damage.
Chrysalidocarpus lutescens	Areca palm	M	Red-orange necrosis parallel to leaflet margins and midveins. Initial damage close to petioles with progression of injury toward leaflet tip. Edges encroached upon last. Mature "middle-aged" leaves most susceptible.
Codiaeum variegatum	Croton	VL	No damage.
Eucalyptus amplifolia	Cabbage gum	H	Interveinal and marginal tan-orange necrosis. Severe cases only midvein remains green.
E. robusta	Swamp mahogany	H	Interveinal and marginal tan necrosis. Severe cases only medvein remains green. Leaf may curl at tip.
E. torreliana	—	H	Bronze to pale orange interveinal necrosis. In severe cases only major veins remain green.
E. viminalis	Manna gum	H	Tan edge and interveinal necrosis. In severe cases only midvein remains green.
Ficus benjamina	Weeping fig	VL	No damage.
Hibiscus rosa-sinensis	Hibiscus	M	Sepal tip burn is initial damage, even in absence of foliar necrosis. Foliar and sepal necrosis is tan. Foliage has marginal and interveinal scorch. Tips of toothed leaf margin burn first. Chlorosis may occur in foliage within 24 hours of SO_2 exposure, with or without necrosis. Defoliation follows chlorosis.
Ligustrum japonicum	Privet	VL	No damage.

TABLE 1 CONTINUED.

Species	Common name	Sulfur dioxide susceptibility[z]	Symptoms associated with injury
Nerium oleander	Oleander	H	Marginal necrosis, tan to brown. Tips burn as edge burn proceeds toward tip. Mature leaves in middle portion of plant most susceptible. Also suckers very susceptible.
Pinus Elliottii	Slash pine	M	Orange tip burn.
Pittosporum Tobira	Pittosporum	VL	No damage.
Quercus virginiana	Live oak	L	Rust-colored interveinal and marginal necrosis. Apical and basal areas of plant most susceptible.
Tipuana Tipu	Rosewood	H	Brown interveinal necrosis. Some marginal necrosis in severe cases.

[z]Class of susceptibility to acute damage by airborne sulfur dioxide: VL = very low; L = low, M = moderate, H = high, and VH = very high.
[y]Injury to leaves alone; plants were not flowering at time of exposure.

Results and Discussion

There was a wide range in susceptibility among the plants tested (Table 1). Symptoms of acute SO_2 exposure were similar among susceptible species and appeared as marginal and interveinal foliar necrosis. Lesions varied in color from rust in azalea, to orange in slash pine, gray in geranium, and white in asparagus fern. Hibiscus was unusual because it developed scorch symptoms as well as chlorosis. Chlorosis was not necessarily associated with scorch and was usually followed by defoliation. This chlorotic condition occurred within 24 hrs of exposure to SO_2.

The pattern of symptom development varied among species. For instance, geranium developed only marginal foliar necrosis following SO_2 exposure at 0.5 ppm for 8 hrs. But 2.0 ppm SO_2 for 2 hrs induced interveinal necrosis as the dominant symptom. In other plants, such as azalea, symptom development was similar at all levels of SO_2 studied. The most interesting response was among marigold cultivars. Fifteen of 39 cultivars studied were scorched selectively at the extra-floral nectaries located along the margins of the leaves, whereas the other cultivars were not affected at the nectaries.

Flowers and flower associated parts were generally uninjured by acute SO_2 levels; however, there were exceptions. Begonia petals occasionally had marginal scorch following exposure to SO_2. Sepals on geranium and marigold were the organs most susceptible to SO_2 induced injury. Sepals were burned first with SO_2 exposure, and at low levels of SO_2, only sepal injury occurred. Geranium sepals had only tip burn, but marigold sepals had tip burn and/or pinpoint necrotic areas scattered over the entire sepal area.

Growers and homeowners should be cautioned that SO_2-induced injury may be similar in appearance to injury due to other causal agents. Pesticide damage, chilling injury and insect damage can be confused with air pollution injury. Proximity of a pollution source, atmospheric conditions, geographical and topological features, and the correlation of other types of plants showing symptomology typical of SO_2 damage must all be carefully examined to diagnose injury as possibly being caused by SO_2. There is not a satisfactory chemical method using fresh plant material which presently can be used to quantify the occurrence of SO_2 exposure.

Literature Cited

1. Adedipe, N. O., R. E. Barrett, D. P. Ormrod. 1972. Phytotoxicity and growth responses of ornamental bedding plants to ozone and sulfur dioxide. J. Amer. Soc. Hort. Sci. 97(3):341-345.
2. Anon. 1978. Effects of atmospheric sulfur dioxides and related compounds on vegetation. *In* Sulfur Oxides. National Academy of Sciences, Washington, D.C. p 80-129.
3. Barrett, T. W., and Benedict, H. M. Sulfur Dioxide. *In* Recognition of air pollution injury to vegetation: A pictorial atlas, J. S. Jacobson and A. C. Hill (ed.). Air Pollution Control Assoc., Pittsburgh, PA. C1-C17.
4. Loomis, R. C. and W. H. Padgett. 1975. Air pollution and trees in the east. U.S.D.A. Forest Service, State and Private Forestry, Northeastern Area and Southeastern Area. 28 pp.
5. Marchesani, V. J. 1975. A comparison of two systems for the bioassay of sulfur-dioxide air pollution effects on vegetation. PhD thesis, Rutgers University. 102 pp.
6. Skelly, J. M. and R. C. Lambe. 1974. Diagnosis of air pollution injury to plants. Extension Division, Virginia Polytechnic Institute and State University. Publication No. 568. 16 pp.
7. Urone, P. and M. A. Kenney. 1980. Atmospheric pollution. *In* Coal Burning Issues, A.E.S. Green, ed. University Presses of Florida, Gainesville, FL. pp. 169-186.
8. Woltz, S. S. and T. K. Howe. 1979. Effects of airborne sulfur dioxide on Florida vegetation. Bradenton AREC Research Report. GC1979-17. 6 pp.
9. Woltz, S. S. and J. J. Street. 1980. Agriculture. *In* Coal Burning Issues, A.E.S. Green, ed. University Presses of Florida, Gainesville, FL. pp 249-276.
10. ——— and W. E. Waters. 1978. Airborne fluoride effects on some flowering and landscape plants. HortScience 13:430-432.
11. Zimmerman, P. W. and A. E. Hitchcock. 1956. Susceptibility of plants to hydrofluoric acid and sulfur dioxide gases. Contrib. Boyce Thompson Inst. 18:263-279.