TREES AS BIOLOGICAL FILTERS[1]

by Bruce R. Roberts

Recent developments in U.S. energy policy suggest that alternative fuel sources will play an increasingly important role in satisfying our future national energy needs. This prospect can be viewed as both good and bad news. The good news is that reduced dependence on foreign oil should reflect positively on our economic situation and thus provide this country with the confidence that would come with energy self-reliance. The bad news is that certain environmental standards will undoubtedly have to be compromised to obtain the energy independence we so desperately need. Despite our personal views on energy and the environment, as professional arborists we need to be concerned about the care and maintenance of trees under constantly changing environmental conditions. Part of this concern involves an understanding of trees and their potential role as biofilters.

In 1971, at our annual convention in Montreal, I presented a brief review of current knowledge on the so-called "sink effect" in trees. Subsequent to that report, and with the interest and financial assistance of ISA through the ISA Research Trust Grant program, we initiated a series of studies on trees as biological filters. I would like to take this opportunity to share with you some of the more important results of this research program.

In our initial studies, container-grown seedlings of white birch (*Betula papyrifera* Marsh.), red maple (*Acer rubrum* L.), white ash (*Fraxinus americana* L.), sweetgum (*Liquidambar styraciflua* L.) rosebay rhododendron (*Rhododendron maximum* L.), kurume azalea (*Rhododendron obtusum japonicum* (Maxim.) Wils. cv. Venus), privet (*Ligustrum vulgare* L.) and firethorn (*Pyracantha angustifolia* (Franch.) Schneid.) were fumigated with sulfur dioxide (SO_2) for 1 hour at a concentration of 1.0 ppm (Table 1). The fumigations were performed in a specially designed chamber under carefully controlled environmental conditions. Results of this research show that maple, birch, and sweetgum are capable of filtering greater quantities of SO_2 from the atmosphere than are rhododendron, ash and azalea. Privet and firethorn show an intermediate response.

Table 1. Foliar uptake of SO_2 by various woody plant species fumigated at 1.0 ppm for 1 hr in an open system*

Species	*SO_2 uptake*	
	mg SO_2/hr/dm^2	*mg SO_2/hr/g*
Red maple	0.088^{a}	0.260^{a}
White birch	0.086^{a}	0.268^{a}
Sweetgum	0.074^{ab}	0.267^{a}
Firethorn	0.072^{ab}	0.213^{ab}
Privet	0.068^{ab}	0.134^{bc}
Rhododendron	0.056^{ab}	0.079^{c}
White ash	0.046^{b}	0.118^{c}
Azalea	0.044^{b}	0.072^{c}

*Mean separation in columns by Duncan's multiple range test, 5% level. (*From:* Roberts, B.R. 1974. Foliar sorption of atmospheric sulfur dioxide by woody plants. Environ. Pollut. 7:133-140).

We have also investigated the biofiltraton of ozone (O_3) by leaves of several shade trees including white birch, red maple, white ash, sweetgum, white oak (*Quercus alba* L.), sugar maple (*Acer saccharum* Marsh.), Ohio buckeye (*Aesculus glabra* Willd.), redvein maple (*Acer rufinerve* Sieb & Zucc.) and coliseum maple (*Acer cappadocicum* Gleditsch.) (Table 2). In these experiments we found that oak and birch filtered the largest quantities of O_3, and red maple and ash the least. The remaining species showed intermediate responses.

From the results of these early investigations with O_3 and SO_2, it is obvious that there are substantial differences in the abilities of various species to filter gaseous contaminants from the air. In addition, we also observed significant inter- and intraspecific variation in foliar uptake of O_3 among four seed-source progenies of the same species (Table 3). In that study, red maple seedlings from Pennsylvania demonstrated a greater

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O_3 filtering capacity than comparable red maples from Alabama, Minnesota and Maine. The data emphasize the important genetic variation that exists in the biofiltration potential of various trees.

Since ambient air pollutant levels are highly variable, especially in and around major urban and industrialized areas, we investigated the possibility that changes in pollutant concentrations might alter the plant's uptake potential. Containerized seedlings of white birch, white ash, firethorn and azalea were fumigated with SO_2 at concentrations of 0.2, 0.5 and 1.0 ppm. While the filtering capabilities of ash and azalea were not influenced by levels of SO_2, seedlings of birch and firethorn exhibited considerably less uptake at 0.2 ppm than at the higher concentrations tested (Table 4). Such species variation probably reflects differences in stomatal response to SO_2, and is a phenomenon that needs additional research.

To test whether the biofiltration of air pollutants is constant over extended periods, seedlings of white birch and red maple were exposed to 0.2 ppm O_3 for periods up to 8 hours. The results show that, under favorable environmental conditions, the uptake of gaseous contaminants can be maintained at relatively constant rates for considerable periods of time (Fig. 1). Under field conditions, however, uptake rates such as those recorded in the laboratory could probably not be sustained. This is so because the microscopic pores (stomata) in the leaf surface through which gaseous pollutants enter the plant are very much affected by changing environmental conditions. Thus, alterations in light intensity, relative humidity, air temperature, wind velocity, etc. would be expected to influence stomatal opening which, in turn, would limit the quantity of contaminants absorbed by the plant.

To better understand the influence of changing environmental conditions on the uptake of air pollutants by trees, we exposed individual leaves of intact Norway maple seedlings (*Acer platanoides* L.) to 1.0 ppm SO_2 at different temperatures and light intensities. As suspected, when light intensity is decreased from 2500 to 500 ft-c, the biofiltration potential of Norway maple declines correspondingly (Fig. 2). However, we also observed a reduction in SO_2 uptake as the temperature increased from 21 to 27°C (Fig. 3). This result was unexpected and may have been caused by changes in CO_2 concentration which were not controlled, and which are known to influence stomatal opening.

In discussing trees as biological filters, we must be aware of the fact that gaseous pollutants may not only be absorbed through stomatal pores, but may also be trapped on leaf surfaces. This pro-

Table 2. Rates of O_3 uptake by 9 shade tree species from an atmosphere containing 0.2 ppm O_3.

Species	*O_3 uptake*	
	mg O_3/hr/dm^2	*mg O_3/hr/g*
White oak	*0.635^a*	*1.318^b*
White birch	*0.536^{ab}*	*2.347^a*
Colesium maple	*0.502^b*	*0.991^c*
Sugar maple	*0.371^c*	*0.863^c*
Ohio buckeye	*0.362^c*	*0.927^c*
Redvein maple	*0.285^{cd}*	*0.911^c*
Sweetgum	*0.278^{cd}*	*0.854^c*
Red maple	*0.272^{cd}*	*0.555^d*
White ash	*0.239^d*	*0.562^d*

**Mean separation in columns by Duncan's multiple range test, 5% level. Values represent the mean of 16, 42, 28, 16, 16, 28, 44, 88 and 20 seedlings, respectively. (From:* Townsend, A.M. 1974. Sorption of ozone by nine shade tree species. J. Amer. Soc. Hort. Sci. 99: 206-208).

Table 3. Rates of O_3 uptake by 4 seed-source progenies of red maple from an atmosphere containing 0.2 ppm O_3.*

Seed Source	*O_3 uptake*	
	mg O_3/hr/dm^2	*mg O_3/hr/g*
State College, PA	0.315^a	0.634^a
Opelika, AL	0.217^b	0.490^b
Alfred, ME	0.266^{bc}	0.557^{ab}
Ely, MN	0.231^c	0.545^b

*Mean separation in columns by Duncan's multiple range test, 5% level. Values represent the means of 20, 26, 22 and 20 seedlings, respectively. (*From:* Townsend, A.M. 1974. Sorption of ozone by nine shade tree species. J. Amer. Soc. Hort. Sci. 99: 206-208).

Table 4. The effect of different concentrations of SO_2 on the foliar uptake of SO_2 by four woody plants.*

OS_2 Concn (ppm)	*SO_2 uptake (mg/hr/g)*			
	Birch	*Ash*	*Firethorn*	*Azalea*
1.0	*0.268^a*	*0.115^a*	*0.222^a*	*0.071^a*
0.5	*0.260^a*	*0.109^a*	*0.218^a*	*0.069^a*
0.2	*0.214^b*	*0.112^a*	*0.178^b*	*0.077^a*

**Mean separation in columns by Duncan's multiple range test, 5% level. (From:* Roberts, B.R. 1974. Foliar sorption of atmospheric sulfur dioxide by woody plants. Environ. Pollut. 7:133-140).

cess, referred to as adsorption, is also an effective means of filtration by many plants. In studies at Delaware, we compared the filtering capacity of rhododendron (*Rhododendron catawbiense* Michx. cv. Nova Zembla) and firethorn (*Pyracantha coccinia* M.J. Roem. var. Lalandii (Duren)Dipp.) in atmospheres containing 0.5 ppm SO_2. We observed substantially greater filtration potential (58% more) with the latter species. Scanning electron microscopy studies of both species showed the leaf surfaces of rhododendron to be smooth and glaucous, whereas those of firethorn exhibited numerous simple trichomes originating on the edges and from the veins (Fig. 4). These morphological features not only permit the trapping of gaseous contaminants directly, but they effectively increase the available adsorptive surface area of this species.

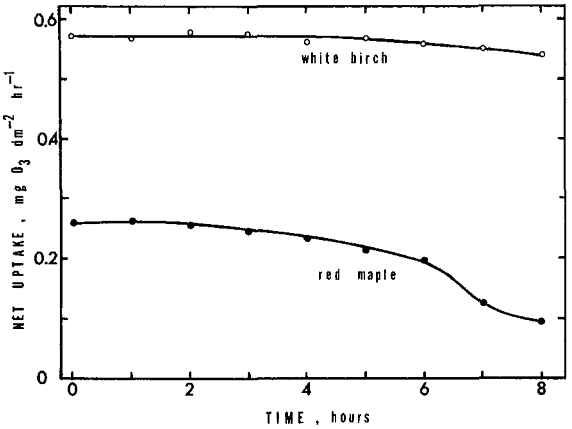

Figure 1. Net ozone uptake by foliage of red maple and white birch seedlings in relation to fumigation time. Rate of uptake measured at 0.2 ppm (*From:* Townsend, A.M. 1974. Sorption of ozone by nine shade tree species. J. Amer. Soc. Hort. Sci. 99: 206-208).

An important aspect of the biological filtering phenomenon in plants is an understanding of what happens to air pollutants once they enter the leaf. Our knowledge is somewhat limited in this area, due in part to the contradictory nature of air pollutant effects. For example, SO_2 can be nutritionally important to plants in some instances, while in other circumstances it may cause severe injury to the same individual. Obviously, we are dealing with a series of complex chemical and biological interactions. As a result of recent investigations with SO_2, we can speculate on a generalized sequence of events related to the interaction of this particular pollutant. There seems little doubt that the primary pathway into the leaf occurs through individual stoma. Once inside the stomatal cavity, SO_2 is chemically changed at a very rapid rate into two inorganic sulfur forms, sulfite sulfur (SO_3=) and sulfate sulfur (SO_4=). Although a portion of this sulfur remains in the inorganic form, the remainder is chemically changed again and subsequently transferred to various organic sulfur com-

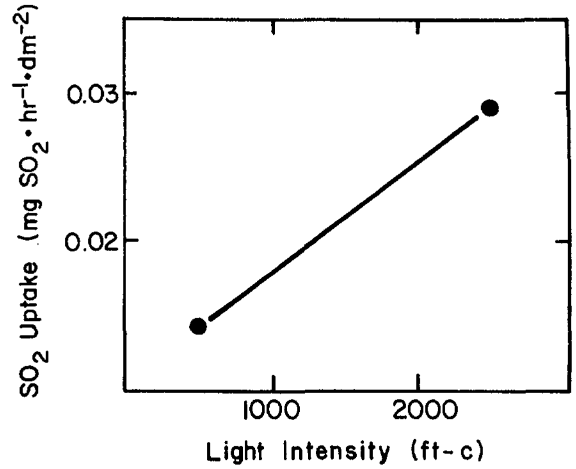

Figure 2. The effect of light intensity on the foliar uptake of SO_2 by seedlings of Norway maple.

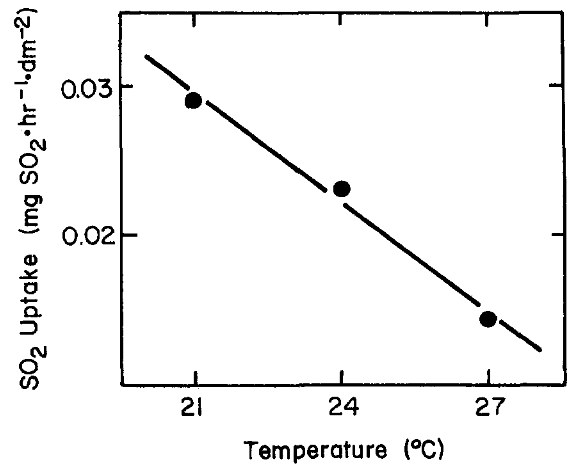

Figure 3. The effect of air temperature on the foliar uptake of SO_2 by seedlings of Norway maple.

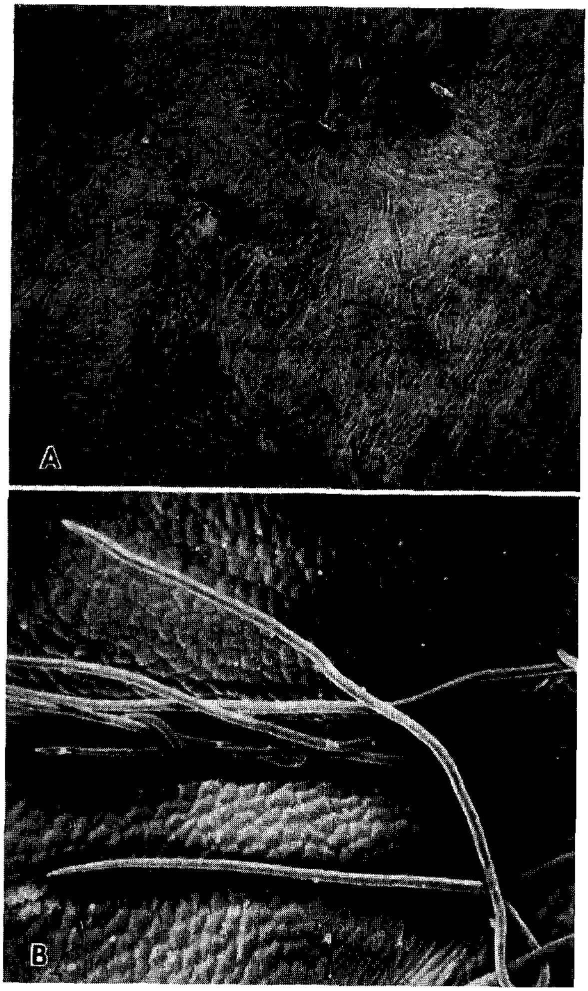

Figure 4. Scanning electron photomicrographs (100 ×) of leaf surface features of *Rhododendron catawbiense* (A) and *Pyracantha coccinea* (B). Arrows indicate simple trichomes. (*From:*Roberts, B.R. and C.R. Krause. 1976. Changes in ambient SO_2 by rhododendron and pyracantha. Hort Sci. 11:111-112).

pounds. The organic forms of sulfur play an important role in plant nutrition. However, as exposure to SO_2 increases, the ratio of inorganic to organic sulfur becomes proportionately greater, resulting in an overabundance of inorganic sulfur (SO_3= and SO_4=) which subsequently reduces normal enzyme and membrane activity in the cell (Fig. 5).

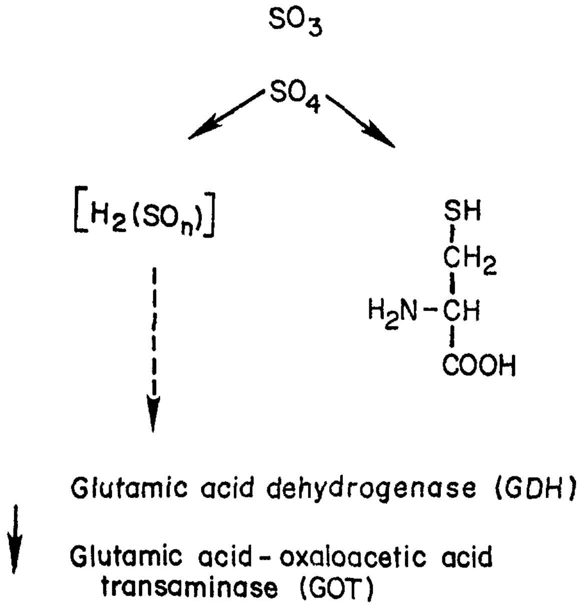

Figure 5. Proposed mechanism of action of sulfur dioxide on plant metabolism.

From this rather brief discussion it is apparent that there is a great deal we don't know about trees as biological filters. Nonetheless, we have made substantial gains in our understanding of some of the important interactions which occur between air pollutants and green plants. Continued research efforts will provide the knowledge and skill required to use trees effectively and efficiently in urban environments.

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