IMPLICATIONS OF GENETIC VARIATION IN HOST RESISTANCE TO AIR POLLUTANTS 1/

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Abstract.--Reports of inter- and intraspecific variation in response of forest trees to air pollutants are summarized. Examples of variation in host response to sulfur dioxide, ozone, fluorides, and roadside salt sprays are included. Potential uses of this inherent variation include: 1. breeding trees capable of surviving under either the severely polluted conditions in large industrial and urban complexes or chronic air pollution that exists over much of the U.S.; 2. developing trees with a readily identifiable air pollution-induced symptom expression and with both a range of sensitivity to one pollutant and differential response to several pollutants for use as bioindicators in air monitoring networks; and 3. breeding trees with a high pollutant absorption and deactivation capacity that would serve as air purifiers.

Additional keywords: Forest trees, sulfur dioxide, ozone, tree breeding, bioindicators, pollutant absorption.

INTRODUCTION

Recognized air pollution-induced injury to forest trees in the U.S. historically has been localized in relatively small, isolated areas. For example, severe damage to forest trees within 25 miles of ore smelters at Anaconda, Montana (Scheffer and Hedgcock, 1955) and Cooper Hill, Tennessee (Hepting, 1964) has been observed since the 1930's. Recently, there has been a trend of increasing air pollution damage to forest trees in natural stands and plantations located far from industrial or urban complexes. In California, injury to ponderosa pine (Pinus ponderosa Laws) and Monterey pine (Pinus radiata D. Don) stands has been reported at distances of up to 80 miles from the cities of Los Angeles and San Francisco (Miller and Millecan, 1971). In California, Maryland, Ohio, and West Virginia, Christmas tree growers have been experiencing increasing air pollution injury in their plantations (Dochinger, 1970, 1973; Miller and Millecan, 1971). Air pollution-induced damage to eastern white pine (Pinus strobus L.), in the form of a symptom complex termed chlorotic dwarf or needle tipburn, has become a wide-spread problem throughout the range of eastern white pine (Dochinger, 1972). The vulnerability of valuable genetic material in seed orchards and arboreta is evidenced by the reported occurrence of pronounced

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needle tipburn and subsequent tree mortality in three white pine provenances in the Beech Creek seed orchard in western North Carolina (Cordell *et al*., 1973).

While a considerable amount of literature has developed on inter- and intraspecific variation in response of forest trees to air pollutants, little practical application has been made of this variation. This paper discusses examples of genetic variation in response to air pollutants and suggests potential uses of this variation.

DISCUSSION

Inter- and Intraspecific Variation in Response of Forest Trees to Air Pollutants

Evidence from field observations in highly polluted areas as well as from controlled-environment fumigation studies suggests that there is a wealth of interspecific variation in the response of forest trees to air pollutants. In general, conifers are more sensitive to air pollutants than are broadleaved trees. There are several exceptions, however, and as can be seen in Table 1, species differences occur in coniferous as well as broadleaved trees.

Significant intraspecific variation in the response of forest trees to air pollutants has been demonstrated by several researchers (Table 2). In studies conducted at the University of Wisconsin, we have attempted to characterize the range of variation in response of local populations of eastern white pine (Houston, 1974) and trembling aspen to SO2, 03, and SO2 plus 03. Houston (1974), using eastern white pine clones classed as either tolerant or sensitive to air pollution, found that the tolerance classes chosen in the field corresponded quite well with those determined by controlled fumigations with SO2 and SO2 plus 03. Sensitive clones were consistently injured more frequently and more severely than were tolerant clones. For example, at 2.5 pphm SO2 plus 5 pphm 03 for 6 hr all sensitive clones tested showed injury while no tolerant clones were injured. Variation in tolerance also occurred within the 2 classes as shown by the fact that only 1 of 5 sensitive clones tested was injured by 2.5 pphm SO2 for 6 hr and that only 3 of 5 tolerant clones were injured by 15 pphm SO2 for 6 hr.

In a comparable study utilizing 5 trembling aspen (*Populus tremuloides* Michx.) clones, I have found a wide range of variability in SO2 and 03 threshold levels. For 3 hr exposures to SO2 the threshold levels varied from 35 to 65 pphm. For 03, threshold levels varied from 5 to 20 pphm for 3 hr.

A series of fumigations with combinations of SO_2 and 03 revealed similar variation in response. While ramets from 2 of 5 trembling aspen clones were substantially injured by a low-level combination (20 pphm SO2 plus 5 pphm 03), ramets from 1 clone showed only light injury following 8 hr exposures to 140 pphm SO2 plus 15 pphm 03.

Table 1.--Reported examples of interspecific variation in tolerance of forest trees to air pollutants

Species	Pollutant and/or Susceptibility	Reference
White ash, green ash, sweetgum, pin oak, scarlet oak, white oak, tuliptree, Japanese larch, European larch, jack pine, Austrian pine, pitch pine, Scotch pine, Virginia pine, Eastern white pine, and Eastern hemlock	Injured by 25 pphm O_3 for 8 hr.	Davis and Wood, 1968, 1972; Wood, 1970
European white birch, little leaf linden, sugar maple, Norway maple, flowering white dogwood, grey dogwood, English oak, red oak, shingle oak, Balsam fir, white fir, Douglas fir, white spruce, Black Hills spruce, Colorado blue spruce, Norway spruce, white cedar and red pine	Not injured by 25 pphm O_3 for 8 hr.	Davis and Wood, 1968,1972; Wood, 1970
Ponderosa pine, Coulter pine, sugar pine, and Jeffrey pine	Differential response to O_3	Evans and Miller, 1972
Sycamore, silver maple, and sugar maple	Severe growth reduction at 30 pphm O_3 for 5 months	Jensen, 1973
Black walnut, green ash, and red maple	Slight growth reduction at 30 pphm O_3 for 5 months	Jensen, 1973
White ash, tuliptree and European black alder	No growth reduction at 30 pphm O_3 for 5 months	Jensen, 1973
Chinese elm	Injured by 2.0 ppm SO_2 for 6 hr.	Temple, 1972
Norway maple	Injured by 3.0 ppm SO_2 for 6 hr.	Temple, 1972
Ginkgo	Injured by 4.0 ppm SO_2 for 6 hr.	Temple, 1972
Pin oak	Not injured by 4.0 ppm SO_2 for 6 hr.	Temple, 1972
Sycamore	Severe injury at 2.0 ppm SO_2 for 3 hr. and moderate injury at .30 ppm O_3 for 3 hr.	Santamour, 1969

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Table 1.--(Cont'd.)

Species	Pollutant and/or Susceptibility	Reference
American elm	Light injury at 2.0 ppm SO_2 for 3 hr. and moderate injury at .30 ppm O_3 for 3 hr.	Santamour, 1969
Jack pine, Eastern white pine, and red pine	Differential response to SO_2 and O_3	Berry, 1971

Table 2.--*Reported examples of intraspecific variation in tolerance of forest trees to air pollutants. Because these were common-environment studies, variation among clones, seedlings, seedlots, and provenances and within seedlots is presumed to be largely genetic in nature. Within-clone variation is thought to be caused by environmental variation within an experiment*

Species	Type of variation	Pollutant	References
Eastern white pine	Among clones	SO_2, O_3	Houston, 1974
Eastern white pine	Among seedlings	SO_2, O_3, HF	Berry, 1973
Eastern white pine	Among saplings	O_3	Botkin, *et al*. 1972
Lodgepole pine	Among provenances	SO_2	Lange, *et al*. 1971
Ponderosa pine	Among seedlings	HF	Adams, *et al*. 1956
Hybrid poplar (*P*. *deltoides* x *trichocarpa*)	Among clones	SO_2	Dochinger, *et al*. 1972
Hybrid poplar	Among clones	O_3	Wood and Coppolino, 1972
Hybrid poplar (*P*. *maximowiezii* x *trichocarpa*)	Within clones	O_3, PAN	Kohout, 1972
Trembling aspen	Among and within clones	SO_2, O_3	Karnosky (Unpublished)
American elm	Among and within clones	SO_2, O_3	Karnosky (Unpublished)
American elm	Among and within seedlots	SO_2, O_3	Santamour, 1969
Sycamore	Among and within seedlots	SO_2, O_3	Santamour, 1969
Red maple	Among provenances	O_3	Townsend, 1974
Sugar maple	Among seedlings	O_3	Hibben, 1969

Potential Uses of Inherent Variation in Host Response to Air Pollutants

Accepting that there is considerable variation in host response to air pollutants, one might ask how this variation could be used in tree breeding programs. Probably the most commonly cited use is to provide a genetic base for breeding trees capable of surviving in polluted air. Among tree breeders this use is somewhat controversial because many researchers feel that we should concentrate on cleaning up the source of air pollution rather than on breeding resistant plants. However, because the task of cleaning up U.S. air pollution problems will be immensely costly and will undoubtedly take several decades, I believe that there is a definite need for breeding air pollution tolerant trees for use in the interim period until we clean up our air.

In addition to developing tolerant trees capable of surviving in polluted air, tree breeders might begin to develop trees with a defined sensitivity range for use as bioindicators in air monitoring networks. With the increasing public concern for environmental impact studies of power plants and other major industries presently under construction, the potential for increased use of biological monitoring programs utilizing forest trees is evident.

Another possible use for inherent variation in host response to air pollutants is to develop pollution-tolerant trees with a high pollutant absorption capacity for planting in greenbelts, parks, and roadside plantations. Besides being aesthetically pleasing and effective in sound absorption, trees can contribute to the health of urban and rural people alike by lowering the atmospheric concentrations of gaseous and particulate pollutants.

Breeding Air Pollution Tolerant Trees

Breeding efforts to develop trees for planting in severely polluted air near large industrial or urban centers historically have been encouraged principally in Europe (Knabe, 1970; Pollanschutz, 1969). Recently, additional needs for air pollution tolerant trees have been recognized. In the U.S., for example, a need has arisen for tolerant Christmas trees to be grown under conditions of low-level (chronic) air pollution. In a survey of air pollution damage to conifers in California, Miller and Millecan (1971) reported that about "10% of the Monterey pine cultivated in 'choose and cut' Christmas tree farms in east Los Angeles and extending eastward to San Bernadino in the south coast air basin were either unmarketable without special treatment or sold at a reduced price because of oxidant injury." Commercial Christmas tree growers in Maryland, Ohio, and West Virginia also have to contend with air pollution injury in their eastern white pine and Scotch pine (*Pinus sylvestris* L.) plantations (Dochinger, 1970; 1973).

A second air pollution problem that warrants the attention of tree breeders is the development of forest trees capable of withstanding the harsh environments created by aerial drift of deicing salts applied for snow removal in the U.S., Canada, and Europe. Davidson (1970) reported that approximately 40% of the 3149 pines planted in 1966 along Michigan highways were dead or in poor condition in 1969. Most of these plants in poor condition exhibited considerable needle desiccation as a result of calcium chloride solutions that drifted onto the needles following the application of salt to the highways. Leaf injury to pines and white cedar trees was found to occur at distances up to 120 m from highways in Ontario (Hofstra and Hall, 1971). Lumis _et al_. (1973) observed injury symptoms on 75 deciduous and coniferous species growing adjacent to roadways in Ontario in a survey designed to evaluate the extent of interspecific genetic variation in sensitivity of trees to deicing salts. Plants with resinous buds, submerged buds, and needle cuticular wax were apparently resistant to damage.

In one of the few forest genetic programs in the U.S. designed to breed air pollution tolerant trees, Gerhold and coworkers have been evaluating Scotch pine seedlings for resistance to SO2 and 03. The selection scheme utilized was described by Demeritt _et al_. (1971). Additional studies of this nature are needed to develop air pollution tolerant trees for an increasing number of both municipal and roadside plantings.

Breeding Trees for Use as Bioindicators in Air Monitoring Programs

To date, most of the air monitoring in the U.S. has been done with chemical monitoring units. However, much of the information supplied by chemical monitoring systems can be obtained from biological monitors (Berry, 1973). In addition to being independent of electricity and free of mechanical breakdowns, such monitors allow us to: "(1) recognize the presence of air-borne contaminants; (2) determine the distribution of the pollutants; (3) estimate the level of pollution; and (4) directly identify some pollutants on the basis of symptoms produced and plant species or clones injured" (Berry, 1973). In addition, bioindicator plants have been used for pollutant collection for later chemical analysis (Hartel and Grill, 1972; Ishin, 1968; Keller, 1974; Lihnell, 1969; McKee and Bieberdorf, 1960).

Because of their pollutant sensitivity, characteristic symptom response, distribution, longevity, low cost, and ease of maintenance, several tree species have been used as bioindicators of urban and industrial pollution (Table 3). Evergreen conifers have the additional advantage of having a 2 to 5 year pollutant record in the form of retained foliage and may show susceptibility during all seasons of the year (Berry, 1973).

Expanded use of trees in environmental monitoring programs will depend largely on (1) calibration of the bioindicator's response to various pollutant doses, (2) development of intraspecific differential sensitivity to several pollutants, and (3) refinement of pollutant injury identification. It is in these areas that there is potential for a substantial contribution from tree breeding programs.

In perhaps the only study of its kind to utilize forest trees, Berry (1973) examined the possibility of selecting eastern white pine genotypes with specific sensitivity to three pollutants. Containerized seedlings were grown for at least one year under each of three different pollutant regimes:

Table 3.--Examples of the use of trees as air pollution bioindicators

Type of Pollution	Primary Pollutant	Species	References
Urban	SO_2	Norway spruce	Hartel and Grill, 1962
	SO_2	Scotch pine	Ishin, 1971
	Oxidants	Incense cedar Ponderosa pine Coulter pine Sugar pine	Miller and Yoshiyama, 1973
	Oxidants	White ash	Keller, 1974; Wood, 1971
Industrial	SO_2	Birch, Apple, Spruce	Lihnell, 1969
	SO_2	Cedar elm and Arizona ash	McKee and Bieberdorf, 1960
	SO_2	American ash Hophornbeam Blackjack oak	Cole, 1958
	SO_2	Eastern white pine	Ellertsen *et al*. 1970
	SO_2	Scotch pine	Knabe, 1970
	SO_2	Loblolly pine	Bierberdorf *et al*. 1958
	Fluorides	Ponderosa pine	Adams *et al*. 1956
	Fluorides	Austrian pine Eastern white pine, Scotch pine, Douglas fir, Norway spruce, red oak, and sycamore maple	Keller, 1974

(1) power plant emissions (SO2); (2) fertilizer plant emissions (flourides); and (3) automobile emissions (oxidants). Of 1428 surviving seedlings, 64 were resistant in all three regimes, 164 were injured in all regimes and 75 were injured in only one regime. Selections of this material are being propagated for use as sensitive bioindicators of air pollution and as resistant lines for use in seed orchards of white pine. Additional work of this nature would improve the potential for utilizing forest trees as bioindicators in air monitoring networks.

Breeding Trees for Pollutant Absorption in Greenbelts, Parks, and Roadside Plantings

Thomas *et al*. (1944) first demonstrated pollutant uptake by plants. It was not until the late 1960's, however, that researchers became aware of the potential role of plants as "air conditioners" in cleansing air of pollutants. Several researchers have since suggested that trees would be efficient pollutant absorbers and aesthetically pleasing plants to use in greenbelts, parks, and roadside plantings (Bernatzky, 1969; Hanson and Thorne, 1970; Lammana, 1970; Robinette, 1968).

Evidence for the tremendous pollutant uptake capacity of forest trees comes from both field observations of pollutant concentrations outside and within forest stands and from pollutant absorption studies in controlled environments. Treshow *et al*. (1973) reported that 03 concentrations within a Utah trembling aspen forest were consistently lower than those measured in clearings. Significantly reduced particulate matter on filters placed under both deciduous and coniferous forest stands when compared with filters located in open terrain has been reported (Anon., undated). Keller (1971) estimated that spruce and beech forests can trap about 32 and 68 tons of dust per hectare per year, respectively. Extrapolating their results of 03 uptake by an alfalfa canopy, Rich and Tomlinson (1970) estimated that "if a polluted air mass containing 150 ppm ozone stood over a forest of trees 15 ft tall for one hour, the air filtering down to the forest floor would contain 60 to 90 ppm of ozone. After eight hours, the air filtering down would have only 30 ppm ozone left".

The potential for breeding air pollution tolerant trees with a high pollutant absorption capacity is good. Controlled-environment studies have shown that there are significant species differences in foliar absorption rates of SO2 and 03 (Godzik, 1970; Jensen and Kozlowski, 1974; Roberts, 1974; Townsend, 1974). Godzik showed that eastern white pine absorbed SO2 more readily than Scotch pine, pitch pine (*Pinus rigida* Mill.) mugho pine (*P*. *montana* Mill.) and Austrian pine (*P*. nigra Arnold). Eastern white pine absorbed S02 at more than twice the rate of Austrian pine. Roberts (1974) reported that red maple (*Acer rubrum* L.), white birch (*Betula papyrifera* Marsh.), and sweetgum (*Liquidambar styraciflua* L.) showed greater foliar SO2 uptake than did white ash (*Fraxinus americana* L.), rosebay rhododendron (*Rhododendron maximum* L.), or kurkume azalea (*Rhodendron obtusum japonicum* Maxim.).

In a study of 03 uptake by 9 shade tree species, Townsend (1974) found that the 03 uptake rates of white oak (Quercus *alba* L.) and white birch, the most efficient 03 absorbers, were more than twice those of the least efficient, red maple and white ash. Coliseum maple (*Acer cappadocicum* Gleditsch), sugar maple (*Acer saccharum* Marsh.), redvein maple (*Acer rufinerve* Sieb. and Zucc.), Ohio buckeye (*Aesculus* glabra Willd.), and sweetgum had intermediate 03 removal rates. Significant differences in 03 uptake were also found among 4 red maple seed source progenies.

Jensen and Kozlowski (1974) showed interspecific variation in SO2 uptake by red maple, largetooth aspen (*Populus grandidentata* Michx.), white ash, and yellow birch (*Betula alleghaniensis* Britton). They found that largetooth aspen had the highest absorption rate while red maple had the lowest rate. Translocation of absorbed S^{35} 02 was followed for 8 days after an 8 hr fumigation. For the first 4 days, most of the radioactive sulfur was found in leaves but by day 8, large amounts were found in the roots indicating the potential for soil deposition of atmosphere pollutants by forest trees. The amounts of sulfur translocated to the roots varied with species.

Selection of trees for planting in areas of high air pollution thus could be done on the basis of both pollutant tolerance and pollutant absorption ability (Townsend, 1974). Further studies by tree breeders would be beneficial in establishing species and cultivar recommendations for such plantings.

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