Air Pollution: Effects on Plants

Most people worry—justifiably—about the effects of air pollution on human health. But there is another aspect of the problem that receives less popular attention. Air pollution may injure many species of plants with consequent economic or aesthetic losses.

Plants may be affected by relatively low concentrations of pollutants and can serve as a kind of early warning system for the buildup of noxious chemicals in the air. In fact, plant and crop damage around Los Angeles in the 1940's alerted investigators to a developing problem in urban areas—a problem that was to become all too familiar as "smog." Ozone and other oxidants were identified as the smog components causing the damage. Today, according to most estimates, ozone accounts for as much as 90 percent of pollution injury to vegetation.

Few Generalizations Possible

After that generalization, few others are possible about the effects of air pollution on plants. Some of the many variables known to affect the extent of injury to plants include the genetically determined susceptibility of the plant; its stage of development; climatic factors such as temperature, humidity, and the intensity and duration of sunlight; interactions between pollutants; the time of day of exposure; and soil moisture.

Moreover, plant pathologists distinguish between injury to the plant and damage, which they define as economic loss. For example, a plant may be injured without damage if its yield or esthetic value is unaffected. Conversely, some investigators have evidence that decreased yields can occur in the absence of easily identifiable symptoms of injury. All these factors make assessment and prediction of the economic losses caused by air pollution very difficult.

A large number of crops, however, are known to be injured—and damaged—by air pollution. A partial listing would include potatoes, sweet corn, tomatoes, green beans, pinto beans, lima beans, grapes, oranges, tobacco, spinach, peanuts, soybeans, and alfalfa. For example, in the summer of 1971, the potato crop on the eastern shore of Virginia suffered damage of up to 50 percent of some varieties from oxidant pollution.

Howard Heggestad and his colleagues at the Air Pollution Laboratory of the U.S. Department of Agriculture (USDA) in Beltsville, Maryland, have compared the effects of ambient air and charcoal-filtered air on the growth and yields of potato varieties grown in greenhouses. Filtering the air removes almost all of the oxidants. They found that some varieties were very sensitive to oxidants. Their leaves were severely injured, and, since this cuts down their photosynthetic capacity, the potato yields were sharply reduced. Other varieties were resistant and suffered little damage.

The leaves are usually the site of injury by gaseous pollutants, including oxidants. They enter the leaves through small openings called stomata that are necessary for normal exchange of gases by the leaf. The characteristic symptom of acute ozone toxicity is the presence of necrotic or dead spots, mostly on the upper leaf surface.

Most investigators think that acute exposures to ozone alter the permeability of cellular and subcellular membranes. Ozone may act by oxidizing sulfhydryl groups needed for enzyme activities or by oxidizing lipids and other membrane constituents. With their electrolyte and nutrient balances disturbed, the cells collapse and die.

Other examples of crop plants injured by oxidants include grapes, navel oranges, and alfalfa. According to experiments performed by C. Ray Thompson at the Air Pollution Research Center of the University of California at Riverside, oxidants may decrease the yields of these crops by as much as 50 to 60 percent. Furthermore, the studies indicated that in the Los Angeles basin, where Riverside is located, oxidants other than ozone contribute significantly to the damage.

These may be nitrogen dioxide or peroxyacetyl nitrate (PAN), both constituents of photochemical smog. Studies by O. Clifton Taylor and others at Riverside have shown that both of these substances may injure plants, although PAN is by far the more toxic of the two. It is also several times more toxic than ozone but is normally present in much lower concentrations.

One of the more spectacular examples of pollution injury is found in the San Bernardino National Forest, approximately 80 miles east of Los Angeles. More than 100,000 acres, out of a total of 160,000 in the forest, have been severely or moderately damaged. According to Paul Miller of Riverside, the damage is caused mainly by ozone, the primary pollutant in the area, and other oxidants. Additional forested areas of California are suffering similar damage.

California and the Northeast from Washington, D.C., to Boston have the biggest problems with pollution-damaged plants. Although ozone concentrations are about three times greater near Los Angeles than they are in the Northeast, plants in the latter region may be more sensitive to the pollutant. This is because high humidity and high soil moisture, which are more common in the Northeast, increase the severity of injury by ozone.

Still, damage in the Los Angeles basin can be severe; ozone concentrations there can go as high as 70 parts per hundred million (pphm). For comparison, the air quality standard for ozone that has been established by the Environmental Protection Agency (EPA) is an average concentration of 8 pphm during a period of 1 hour.

Source of the Oxidants

Most investigators think that urban areas with their high automobile densities are the source of the oxidant problem. Hydrocarbons and nitrogen dioxide present in auto emissions react with oxygen in the presence of sunlight to form ozone and PAN (photochemical smog). But elevated ozone concentrations are not restricted to cities. A number of investigators, such as Lyman Ripperton of Research Triangle Institute in North Carolina and Francis A. Wood of the University of Minnesota, have found ozone concentrations exceeding the EPA standard in nonurban areas of several states including Maryland, West Virginia, California, Florida, New York, Wisconsin, and Minnesota.

The idea is that photochemical smog is produced from the auto emissions as air from the cities moves into nonurban areas. Oxidants may actually reach higher concentrations many miles downwind from cities than in the cities themselves. This is because the reactions causing the buildup of ozone are slow and allow time for the air mass to move away from the city. Also, city air contains materials that react with ozone and break it down. Other possible sources of the elevated ozone in nonurban areas are the stratospheric layer and electrical discharges such as lightning.

Most investigations of the effects of air pollution on plants have been concerned with acute exposures to one pollutant. Ambient air usually contains mixtures of noxious chemicals, however, and investigators are giving increasing attention to how they interact in producing their effects on plants. Again, no generalizations can be made. There is evidence that mixtures of two pollutants can act synergistically to produce greater effects than either would if present by itself in the same concentration. Harry Menser, now with

Speaking of Science

Communicating Mathematics: Is It Possible?

The problem of making mathematics understandable to the educated layman continues to be almost insurmountable.
—The Mathematical Sciences: A Report (*National Academy of Sciences, Washington, D.C., 1968*).

The National Science Foundation (NSF) is trying to explain mathematical research to the general public, but it is meeting with resistance from both mathematicians and the public. The NSF has hired a mathematician—Lynn Steen of St. Olaf's College in Northfield, Minnesota—to write nontechnical articles about mathematics for general interest magazines and newspapers and to study the problem of communication between mathematicians and the rest of the world. And, for the first time, organizers of the annual meeting of the American Mathematical Society and the Mathematical Association of America encouraged the press to cover their meeting. However, few articles about mathematical research have been published by the popular press, and only 4 out of the 80 members of the press who were invited to a press luncheon at the annual meeting decided to attend.

Most mathematicians agree that there is a nearly complete lack of communication between themselves and the general public. They differ, however, as to whether this situation can, or should, be changed. According to Steen, about two-thirds of the mathematicians he approached at the International Congress of Mathematicians in Vancouver, British Columbia, last summer were uninterested in explaining mathematics to those outside the field. Such an attitude is consistent with what Steen describes as a tradition in mathematics of emphasizing research communications rather than exposition. This emphasis was expressed by Fritz John of the Courant Institute of New York University who, when asked about his goals as a mathematician, said he was not interested in fame, fortune, or public acclaim but wanted only "the grudging admiration of a few colleagues."

Some mathematicians are enthusiastic about the possibility of explaining their subject to the general public, but even most of these researchers concur that the task may be nearly impossible. The problem, they agree, is caused by the language of mathematics. Although English and the mathematical language have common words such as group, field, model, and stability, the mathematical words have precise technical meanings. Johannes Weissinger of the Karlsruhe Institute of Technology in Germany once explained that mathematicians are trained to use only clearly defined terms and concepts. Yet English or other natural languages owe their expressiveness to the ambiguity of their words and phrases. Translating mathematics into English was described by one mathematician as being more difficult than translating Chinese poetry.

A few mathematicians are famous for their ability to explain their subject to others outside their field and often these expositors are among the most able mathematicians. This is no coincidence, according to Ronald Graham of Bell Laboratories in Murray Hill, New Jersey. Graham believes that those researchers who come up with the most innovative or the most profound results have the greatest insight into their subject. Because these people truly understand what they are doing, they can explain it to others. Lesser mathematicians, who extend the work of these leaders, may not have the intuition that leads to the concepts they use in their work.

Dale Lick of Old Dominion University in Norfolk, Virginia, says that mathematicians are finally becoming concerned about how little nonmathematicians know about their subject. This concern, he believes, is stimulated by the bleak employment prospects in mathematics. However, Lick admits that research in mathematics is exceedingly difficult to explain to the general public. An expedient, he suggests, is to seek publicity about other aspects of mathematics, such as employment, applications of mathematics to other fields, and mathematics education.

Although press coverage of other aspects of mathematics may help mathematicians feel that they are doing their part to gain national attention and perhaps increase their allotment of federal funds, nevertheless there remains the major difficulty of explaining to others exactly what mathematicians think about and why they care about their subject. Few mathematicians choose their subject so as to apply it to other fields. Often they choose it because they consider mathematical concepts to be beautiful. And, like other forms of beauty, mathematical beauty is highly subjective and difficult to communicate.—GINA BARI KOLATA the USDA in Morgantown, West Virginia, and Heggestad found that a mixture of ozone and sulfur dioxide injured tobacco leaves at concentrations that had no effects when the two chemicals were present separately.

On the other hand, Walter Heck, David Tingey, and their colleagues at North Carolina State University have observed that a combination of sulfur dioxide and ozone may produce effects that are synergistic, antagonistic (less than either would produce if alone), or merely additive. The type of effect depended on the species of plant and on the ratio of the concentrations of the two gases.

Mixtures of sulfur dioxide with nitrogen dioxide frequently—but not always—produce synergistic effects, according to Heck and Tingey and to A. Clyde Hill of the University of Utah and Jesse Bennett, now at the Air Pollution Laboratory in Beltsville. These two pollutants often occur together because they are both formed during the combustion of fossil fuels, especially coal. Nitrogen dioxide resulting from auto emissions adds to the quantities emitted from power plants.

Air Pollution, Pests, and Disease

Another area of interest is the relationship between air pollutants and pests or diseases. Miller said that oxidant injury weakens the ponderosa pine and makes it more susceptible to attack by the western bark beetle. Most of the pines succumb to the bark beetle rather than as a direct result of oxidant injury. Some leaf diseases caused by fungi are more severe if oxidant injury is also present. But pollution may be just as harmful to other fungal pathogens as it is to the plant. In that case, there may be less disease. Only appropriate environmental field studies can unravel all these relationships.

Another problem confronting investigators is the distinct possibility that chronic exposure of plants to low concentrations of pollutants for prolonged periods may affect yields or the quality of the crop without producing identifiable symptoms of injury. Bennett said that chronic exposures to ozone may age plants prematurely. Thompson found that navel orange yields could be decreased in the absence of visible injury to the leaves.

This may happen because of a decrease in photosynthesis. Hill and Bennett showed that concentrations of ozone that did not produce necrotic

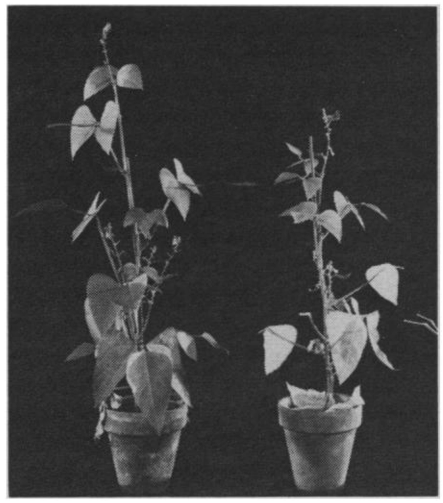

Fig. 1. Differences in response of lima bean varieties to a low concentration of ozone in ambient air during a period of elevated air pollution. The susceptible variety on the right has premature loss of leaves and reduced leaf chlorophyll. [Source: Howard Heggestad, USDA, Beltsville, Maryland]

lesions could reversibly inhibit the apparent rate of photosynthesis. The pollutant probably acts by causing the stomata to close and preventing the uptake of carbon dioxide needed for photosynthesis. Air pollutants may also produce additional subtle effects on plant reproduction, germination, and mutation rates, although this remains to be established.

All these uncertainties make assessment of the cost of pollution damage to plants very difficult. Harris Benedict of Stanford Research Institute has prepared a model for doing this. He concluded, in a study completed in 1971, that the total damage amounts to $132 million each year, a value lower than previous estimates that ranged from $200 to $500 million per year. Benedict's figures do not take into account subtle effects without visible injury. Heck estimates that if they were considered, annual losses to vegetation could amount to up to a billion dollars.

No other pollutants are as prevalent as the oxidants, but more localized pollutants such as sulfur dioxide and hydrogen fluoride have injured vegetation in some areas. Fluorides are emitted during the production of aluminum, steel, ceramics, and phosphorous fertilizers. Plants accumulate fluorides in concentrations far in excess of those in air. This is hazardous, not just for the plants, but also for the animals that eat them. Fluorosis, a sometimes fatal disease of cattle, is caused by high fluoride concentrations in forage.

Sulfur dioxide, which is mainly produced by the combustion of sulfur-containing fuels such as coal and oil, is more widely distributed than fluoride. Problems may arise around power plants, smelters, and ore refineries. In misty weather an acid aerosol can form and injure foliage. Such acid aerosols are distinct from another kind of precipitation called acid rain (or snow) that is receiving increasing attention in this country. A number of investigators, including Wood and Leonard Weinstein and his colleagues at the Boyce Thompson Institute for Plant Research, have found that rainwater may have *p*H values as low as 3.5 to 4.5. The normal value for rain is considered to be about 5.5. The cause of the decreased *p*H and its effects, if any, on vegetation are unknown at this time. In some European countries, however, increased acidity of rain caused by sulfur dioxide emissions has damaged plant life. It has also acidified soils, streams, and lakes in Sweden.

Minimizing the Damage

Since air pollution will remain a fact of life in and around urban centers—especially if emission standards are relaxed or their implementation delayed in an attempt to cope with the ongoing energy crisis—investigators are seeking ways to minimize pollution damage to plants. Plants may be treated with chemicals that oppose the action of the pollutants. Heggestad and Henry Cathey, also at Beltsville, found that the tolerance of petunias to ozone could be increased by treating the plants with a growth retardant. Plants are most sensitive to the action of ozone under conditions that favor rapid growth. The use of antioxidants to retard the action of oxidants is another possibility.

Since chemical treatments are all expensive, use of pollution-resistant plants appears to be a more economical approach. There are marked variations in the susceptibilities of different plant strains to the effects of a given pollutant (Fig. 1). Several investigators said they had projects aimed at identifying or breeding resistant plant varieties. Actually, many plant breeders have inadvertently produced resistant strains simply by conducting breeding experiments in ambient air and selecting the most vigorous plants.

—Jean L. Marx