

POLLUTANTS IN THE AIR AND ACIDS IN THE RAIN¹

by Ellis B. Cowling

As a rule rain is not acid far from towns. If it is acid, artificial circumstances must be suspected.

Robert Angus Smith, 1872.

In the opinion of many philosophers, an important part of our contemporary environmental problems derive from the injunction stated in the sixth chapter of Genesis:

Go, multiply, and subdue the earth and take dominion over every bird of the air and every fish of the sea and every living thing that moves upon the surface of the earth.

Many would agree that both western and eastern peoples have taken this injunction a bit too literally. If given the chance to revise these poetic words, I wonder if we would not write a bit more modestly (but much less poetically!):

Go and multiply with caution—bearing in mind the carrying capacity of the land and seas of the earth. Take a responsible dominion over the renewable and the nonrenewable resources of the earth—remembering that the health and prosperity of the people will be determined by the sustainable productive capacity of the lakes and streams and the fields and forests and the oceans of the earth.

In the Beginning . . .

Since the origin of life on earth, plants, animals, and microorganisms have obtained an important part of their sustenance from the atmosphere—carbon, hydrogen, and oxygen for photosynthesis and respiration; nitrogen and sulfur for synthesis of proteins and amino acids; phosphorus for energy transformations and production of nucleic acids; calcium and magnesium

for structural components; and a host of trace elements—iron, zinc, copper, cadmium, manganese, and boron—to facilitate metabolic transformations. All 16 of these essential elements are dispersed through the atmosphere and are taken up by plants directly through their foliage as well as through their roots.

As the Industrial Revolution gathered momentum in the middle of the 19th century, human activities of many sorts added more and more substances to those that circulate naturally among the air, water, soil, and all living things. Some of these substances are beneficial for agriculture and forestry because they provide nutrients for the growth of crops and forests or accelerate the natural weathering of soil minerals. Other substances are less important because they are inert biologically. Still other substances are detrimental because they cause stress in plants, animals, or microorganisms, alter surface and ground water quality, aggravate nutrient deficiencies in soils, or accelerate the soiling, weathering, or corrosion of engineering and cultural materials.

Everything human beings do on a large scale influences the chemistry of the atmosphere and, in turn, the health and productivity of the ecosystems on which the abundance and quality of our life depends. The largest of all human influences on the chemical climate results from combustion of fossil fuels, urban development, and clearing of land by burning of natural vegetation. These activities include: generation of electricity, mining and smelting of metals, processing and use of petrochemicals, industrial processes of many sorts, use of transportation vehicles, space and water heating, incineration and decomposition of sanitary and solid wastes, use of explosive devices in peace and war, launching of

1. Presented at the annual conference of the International Society of Arboriculture in San Antonio in August 1986.

space vehicles, and agricultural and silvicultural operations involving plowing, cultivating, spraying, disposal of plant and animal wastes, and burning of farm and forest residues.

In recent years, the words "acid rain" have captured the imagination of the people of Europe and North America in much the same way and for substantially the same reasons that Rachel Carson's "Silent Spring" captured our imagination in the early 1960s. But "acid rain" must be recognized as only one special feature of a series of more general subjects that include:

1) The emission, transport, transformation, deposition, and uptake of natural and man-made chemicals from the atmosphere into ecosystems.

2) Wet and dry deposition of beneficial nutrients and injurious gases, aerosols, and dissolved or suspended substances in rain, snow, hail, dew, and fog.

3) The short-distance and long-distance transport of air pollutants from one state or nation to another.

4) The role of human activities as a potent force in the biogeochemical circulation of matter in the earth; and

5) The responsibilities of human beings as managers of industrial societies and custodians of the natural resources of the earth.

The airborne chemicals of major concern to our society are listed in Table 1. They include two major types of pollutants (primary and secondary) and eight specific chemical or physical groups of substances. Primary air pollutants are gases or other volatile waste products emitted directly from stationary or mobile sources. Stationary sources include power plants, metal smelters, and other industrial or commercial installations, as well as domestic and commercial space and water heating units. Mobile sources are mainly cars, trucks, trains, aircraft, and ships. Secondary pollutants include a wide variety of substances

portant source of sulfur oxides in tropical regions of the world.
2) *Nitrogen oxides* (NO_x). Two colorless gases (NO and NO_2) produced in any high temperature process such as combustion of coal, oil, gasoline, and natural gas. NO_x 's are emitted by both stationary sources and transportation vehicles. In tropical countries burning of biomass is also an important source of NO_x .

3) *Toxic elements*. Heavy metals such as lead, cadmium, nickel, and mercury or fluorine and other toxic elements are released mainly by large metal smelters and by transportation vehicles using leaded gasoline.

4) *Volatile organic compounds* (VOC). A wide variety of carbon compounds ranging from such simple molecules as ethylene, gasoline, and cleaning and painting solvents to very complex molecules such as pesticides. VOC are emitted by many different, usually small stationary and mobile sources.

5) *Carbon monoxide* (CO). A colorless and odorless but highly toxic gas produced during incomplete combustion of coal, oil, and natural gas and incineration of garbage and other solid and liquid wastes. Carbon monoxide inhibits respiration in humans and other animals. It is of concern to society mostly in urban areas where it accumulates in stagnant air mainly from transportation vehicles.

6) *Particulate matter* (PM). A catch-all category of pollutants ranging from very coarse "fugitive dust" particles that cause soiling of textiles, windows, paints, etc., to very fine aerosol particles that cause atmospheric haze or are drawn into lungs where they induce respiratory disease. These substances are extremely diverse both chemically and physically. The larger particles range from almost pure carbon in the case of soot from oil burners to mineral dusts in the case of manufacturing facilities that process cement, asbestos, clay, ceramic, glass, textile, and other materials. The fine particles range from smoke to all sorts of sulfate, ammonium, organic, metallic, and other particles formed by condensation of gases, vapors, and other volatile substances in the atmosphere. Some of these particles have very remarkable and complex fine structures that are characteristic of the original sources of the emissions.

7) *Ozone* (O_3) and other photochemical oxidants. These substances include peroxyacetyl nitrate (PAN) and peroxypropionyl nitrate (PPN). They occur only as secondary pollutants which are produced when NO_x and VOC interact with atmospheric oxygen in the presence of sunlight. Ozone is the most important of these three pollutants because it is much more abundant even though it is somewhat less toxic than PAN or PPN. These compounds are among the most toxic gases to which plants, animals, and humans are exposed in the environment.

8) *Acid deposition*. A variety of acidic and acidifying substances produced when gaseous SO_2 , NO_x , HCl, and certain other airborne chemicals interact with oxygen, ammonia, and moisture in the air to give aqueous solutions or aerosols of sulfuric, nitric, and hydrochloric acids. Wet deposition of these substances occurs during all rain, snow, hail, dew, fog, cloud, or rime-ice events; dry deposition occurs at all times—by absorption or adsorption of gaseous SO_2 , NO_x , HNO_3 , and HCl and by impaction of sulfate, nitrate, and chloride aerosols on the surfaces of plants, soils, animals, microorganisms, surface waters, and materials. The acidic and acidifying substances in wet and dry deposition may be partially or completely neutralized by alkaline earth elements such as calcium, potassium, sodium, or ammonium ions. Acidification of ecosystems also occurs when ammonium sulfate aerosol and certain other ammonium compounds or ammonia itself are taken up by plants, animals, or microorganisms after deposition into ecosystems.

Table 1. Air pollutants of major concern to society.
Chemical and physical nature of air pollutants:

1) *Sulfur dioxide* (SO_2). A colorless gas produced during combustion of sulfur-containing materials such as coal, oil, and biomass, and during smelting of sulfide metal ores. SO_2 is emitted mainly by large stationary sources such as fossil fueled power plants, metal smelters, and certain other industrial and commercial installations. Biomass burning is an im-

formed in the atmosphere by chemical transformation of primary pollutants.

The six most important primary air pollutants are sulfur dioxide, nitrogen oxides, toxic elements such as lead and fluorine, a wide variety of volatile organic compounds, carbon monoxide, and particulate matter. The two most important secondary pollutants are photochemical oxidants (especially ozone) and acid deposition. Airborne acids and particulate matter can occur as both primary and secondary pollutants.

The operation of power plants, metal smelters, and motor vehicles all illustrate the dilemma in which we find ourselves. Electricity, metals of various sorts, and transport vehicles are used for many worthwhile purposes in our society. Fossil fuels (mainly coal, oil, and natural gas), and sulfide metal ores are available near the earth surface. The fuels can be burned to generate electricity or to propel motor vehicles. The metal ores can be roasted to separate "the metal" from the sulfur and other "impurities." During these combustion and heating processes, certain waste products are produced. These waste products include sulfur and carbon oxides formed from the fuels and sulfide ores, nitrogen oxides formed mainly from nitrogen in the air, and certain noncombustible materials including various toxic metals. These waste materials accumulate either as a solid (ash) or are released into the atmosphere in a rapidly moving stream of exhaust gases and aerosols.

Various engineering systems are available for decreasing emissions of these air pollutants. Sulfur, for example, can be removed from coal and oil in three ways—prior to combustion by desulfurizing the fuel, during combustion by modifying the combustion process, or after combustion by desulfurizing the flue gases. Use of lead-free gasoline together with catalytic converters and modified combustion systems in automobile engines can greatly decrease vehicle emissions of lead, carbon monoxide, and nitrogen oxides. Unfortunately, these engineering systems have not been installed or are not properly maintained in all power plants, metal smelters, and motor vehicles.

Earlier it was believed that most of the airborne waste products emitted from these stationary and mobile sources fell out of the atmosphere near the

point of emission. Now it is recognized, particularly with increasing use of tall smoke stacks at power plants and metal smelters, that meteorological processes can lead to extensive mixing and to both chemical and physical transformations of millions of tons of gases, fine aerosol particles, and coarse particles that are released into the atmosphere each year.

Recently, fog in industrial regions and cloud water high in the atmosphere were discovered to be much more rich in acids and other air pollutants than rain or snow. This discovery greatly increased concern about possible effects of airborne chemicals on high mountain forests.

These airborne substances and their reaction products are carried by wind and clouds wherever the wind blows and then deposited on the surfaces of vegetation, soils, surface waters, and engineering or cultural materials at short or long distances from the original sources of emission. Thus, the chemical composition of the air, and the rain, snow, dew, hail, fog, and cloud water within any region is a function of all the airborne substances dispersed, mixed, transformed, and transported into the atmosphere of that region and then deposited and taken up by the plants, animals, and microorganisms in terrestrial and aquatic ecosystems.

As indicated earlier, some of these substances are beneficial nutrients that help living things grow. Unfortunately, however, some of these substances are also toxic or otherwise injurious to plants, animals, microorganisms, human beings, engineering materials, and such cultural resources such as the Parthenon in Greece, the Taj Mahal in India, and the Statue of Liberty in the United States.

Natural sources vs. human sources of airborne chemicals. There are some in our society who argue that natural emissions of airborne chemicals are just as important as emissions from human activities. There is a measure of truth in this contention so long as the whole earth is used as the basis for reference rather than just the industrial regions. A Russian soil scientist named Kovda (1975) was among the first to compare the amounts of substances involved in natural processes and human activities. His data are shown

in Table 2. They permit two major generalizations about the relative magnitudes of natural (biogeochemical) and human (anthropogenic) processes:

1) Garbage, urban wastes, and byproducts are now produced at about twice the rate at which photosynthesis occurs in the whole earth; also

2) Industrial dusts, aerosols, and gases are now discharged into the atmosphere at about the same rate as dissolved chemicals drain from all the rivers of the world.

When the question of relative magnitude of human and natural sources of airborne chemicals are restricted to the industrial regions of the world, an even more impressive picture emerges. Galloway and Whelpdale and later Husar have estimated that human activities in North America release about 20 times more sulfur oxides and about 10 times more nitrogen oxides than are produced by all natural sources in this same continental area.

The remarkable rapidity of change in emissions of sulfur and nitrogen oxides in the northern and southern United States during the past century is shown in Figures 1 and 2. Note that the southern states are rapidly catching up with the heavily industrialized northeastern states in terms of emissions per unit area of land. Human activities have indeed become a major force in the biogeochemical circulation of matter in the earth!

The Influences of Air Pollutants on our Natural Environment

Airborne chemicals cause eight different kinds of detrimental or beneficial effects on our society:

- direct effects on human health;
- indirect effects on human health;
- damage to materials;
- increased haze in the atmosphere;
- acidification of lakes, streams, ground waters, and soils;
- fumigation of crops and forests near point sources;
- regional changes in health and productivity of forests; and
- fertilization of crops, forests, and surface waters.

All except the last of these eight effects are detrimental to the interests of society. In fact, even the last has proven to be detrimental in the case of some surface water systems such as Lake Erie and Lake Ontario.

Please note especially that:

- 1) Sulfur dioxide (SO_2) emissions are involved in all eight effects;
- 2) Nitrogen oxides (NO and NO_2) or their photochemical derivatives are involved in seven of the eight effects;
- 3) Volatile organic compounds (VOC) or their photochemical derivatives such as ozone (O_3) are involved in five of the eight effects;

SULFUR EMISSION TREND
NORTH AND SOUTH OF THE OHIO RIVER

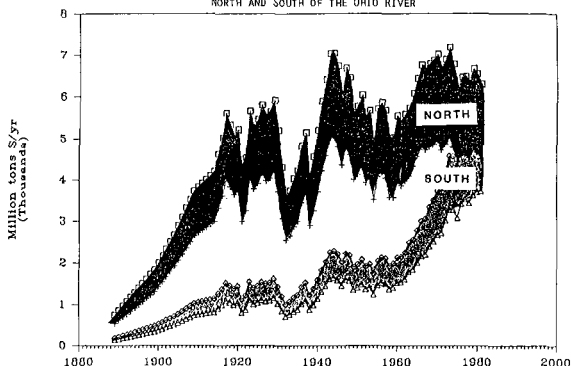


Figure 1. Changes in emissions of sulfur dioxide per unit area of land in the areas north and south of the Ohio River in the eastern United States between 1880 and 1980.

NO_x EMISSION TREND
NORTH AND SOUTH OF THE OHIO RIVER

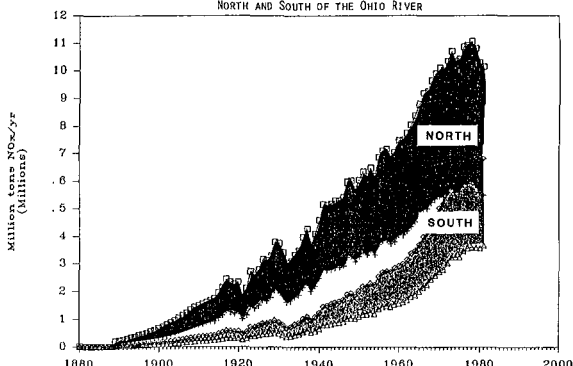


Figure 2. Changes in emissions of nitrogen oxides per unit area of land in the areas north and south of the Ohio River in the eastern United States between 1880 and 1980.

4) All three of these primary pollutants (SO_2 , NO_x , and VOC) are produced during combustion of fossil fuels in power plants, metal smelters, transportation vehicles, and other industrial, commercial, and domestic uses of energy; and

5) SO_2 , NO_x , and VOC are also the most important chemical precursors of photochemical oxidants, acid deposition, atmospheric haze, and certain types of particulate matter which have a wide range of detrimental effects on our society. For this reason, these three primary pollutants are major keys to the proper management of air quality in most industrial regions of the world.

Ecosystem responses to change in the chemical climate. During all the millenia that followed the first development of life on our planet, microorganisms, plants, and animals adapted their habits of growth, nutrition, and metabolism to fit within the dominant physical and chemical features of their environment. The processes of natural selection determine which organisms survive and which organisms perish. If a given organism is well adapted to the environment, it will thrive and reproduce. If it is not fit, it will not survive. When the climate changes, new pressures of natural selection are applied to the population of surviving organisms. These continuing processes of evolutionary change and adaptation have led to the development of the marvelously diverse communities of living organisms that we find everywhere over the land and in the surface waters of the earth.

These natural ecosystems, both terrestrial and aquatic, come as a gift from the evolutionary history of our planet. They are ours to use as we see fit—to manage within the sustainable productive capacity of the resource in question, or to exploit carelessly with little regard to the long-term stability of the ecosystems themselves.

When human beings first appeared on the earth and the process of civilization began, our collective impact on the processes of natural selection and evolution were hardly perceptible. But as we increased in numbers and particularly after we learned to

—harness the energy stored in fossil fuels and to

—apply this energy to the processes of urbanization, industrialization, and intensive

agriculture and forestry, our collective impacts on the processes of natural selection and evolution became progressively more important.

Today, the aquatic and terrestrial ecosystems in certain high elevation, industrial, and urban locations in North America, Europe, Japan, China, South Africa, and some developing countries are receiving much heavier loadings of airborne nutrients, acidic, toxic, and growth-altering chemicals than were deposited in the preindustrial period in which these ecosystems evolved. In some locations, essentially all the nutrients needed to sustain some of these ecosystems are now provided from atmospheric sources (see Tables 1 and 2 and Figures 1 and 2). Never before in their evolutionary history have the terrestrial and aquatic ecosystems of North America and Europe been “fed from above” to the extent that they are today!

Under these new conditions of continuing change in our chemical climate, additional pressures for further adaptation of plants, animals, and microorganisms will be applied and will have their influences within these ecosystems. At present we have only limited experience and even less scientific evidence with which to identify regions where the rates of continuing change in the chemical climate are within the elastic limits of ecosystem resiliency and adaptability and where these rates of change will exceed those limits. Nowhere are these uncertainties more evident than in the forests of central Europe and certain high-elevation forests in eastern North America.

Acute vs. chronic exposures of forests. A great disparity exists in our present understanding of the possible detrimental effects of airborne chemicals on forests. This disparity is between:

—acute exposure to locally dispersed primary pollutants such as sulfur dioxide and hydrogen fluoride and

—chronic exposure to lower concentrations of regionally dispersed secondary pollutants such as ozone and acid deposition.

Steep gradients around point sources of primary pollutants have made it fairly easy to establish a strong correlation between pollutant concentration and visible symptoms of damage and/or death of vegetation. When this strong correlative

evidence has been coupled with the results of a few controlled exposure tests, little scientific uncertainty usually remained about:

- what species of plants are susceptible,
- the source of the injurious substance(s),
- their chemical nature, or
- the concentrations of chemicals that are injurious.

Thus, sensible air-quality and/or forest management recommendations could be formulated on the basis of straightforward relationships between the concentration and time of pollutant exposure (dose) and the change in health or productivity of the forest (response). Only at the fringes of the area affected was there usually much uncertainty about cause-and-effect and/or dose-response relationships or about the complicating role of competition, drought, frost, biotic pathogens, or other natural stress factors.

Cause-and-effect relationships have been much more difficult to establish when chronic exposure to regionally dispersed secondary pollutants rather than locally dispersed primary pollutants are involved. There are several reasons for this: 1) visible symptoms may be subtle or lacking; 2) concentrations of regionally dispersed airborne chemicals are often highly variable; 3) exposure to two or more chemicals may occur simultaneously or sequentially and they may act additively, synergistically, or antagonistically; and 4) rigorous scientific methods must be employed to distinguish the effects of regionally dispersed airborne chemicals from those of natural stress factors which may act as predisposing, inducing, or contributing causal factors.

Regional changes in forest health and productivity. Although a total of 18 regional changes in forest health and productivity have been observed in Europe and North America during the past several decades, regionally dispersed airborne chemicals are considered to be a probable or possible causal factor in only 5 of them. These five are described below in order of decreasing quality of evidence that airborne chemicals have played a crucial role.

1. *Ozone damage to white pine in the eastern United States.* The most rigorous scientific evidence for a regional forest health problem resulting from regional dispersed pollutants is the

case of eastern white pine damaged by ozone within much of its natural range in the eastern United States and Canada. In this case: a) Visible symptoms of damage are correlated with measured geographical gradients in mean ozone concentration or with periodic episodes of high peak concentrations; b) The major visible symptoms of damage have been duplicated in controlled exposures which are similar to the exposures occurring in forests; c) Observed variation in susceptibility to damage between individual trees in the forest has been duplicated in controlled exposures with clonal lines of eastern white pine; and d) Decreases in genetically controlled variation in resistance and susceptibility to ozone have been found in certain provenances of eastern white pine during the past several decades.

2. *Ozone damage to mixed conifer forests in the San Bernardino Mountains of California.* The evidence in this case is slightly less rigorous than that for eastern white pine: a) the frequency of damage to trees is well correlated with geographical gradients in ozone concentration and with distance from Los Angeles—the principal source of precursor nitrogen oxides and volatile organic carbon compounds from which ozone is formed; and b) the major damage symptoms have been reproduced in controlled exposures to ozone. In contrast to the eastern white pine case, death of severely affected trees usually is induced by bark beetles and root-rotting fungi which preferentially attack the ozone-damaged trees.

3. *Waldsterben in Central Europe.* In this case,

Table 2. Biogeochemical and technological forces in the biosphere of the earth.

<i>Biosphere components</i>	<i>Tons per year</i>
Biogeochemical processes.	
Yield of photomass	1×10^{10}
Cycle of inorganic elements	1×10^{10}
River discharges:	
Dissolved substances	3×10^9
Suspended substances	2×10^{10}
Anthropogenic sources.	
Output of fertilizers	3×10^8
Industrial dusts	3×10^8
Garbage, urban wastes, and byproducts	2×10^{10}
Mine refuse	5×10^9
Aerosols and gas discharges	1×10^9

essentially all native and introduced commercial softwood and hardwood tree species are affected—though not to the same degree nor in exactly the same way. At least 10 tree species grown under a wide range of climatic, soil, and site conditions have shown marked decreases in rate of growth over the past 5 to 30 years. During the past 5-8 years, they also have shown various visible symptoms of damage including: a) premature loss of older needles on conifers beginning with the innermost parts of the crown; b) chlorosis in needles; c) atypical branching habit; d) smaller and more irregularly shaped leaves; e) unusually heavy cone crops year after year; f) decreased radial growth; and g) decreased abundance of feeder roots and mycorrhizae. Damaged trees are generally distributed at random mainly in forests over 60 years of age.

Several of these symptoms have never been seen before. The cause(s) are unknown. Less than 5% of the damaged trees have symptoms which can be attributed to insects or disease. Some trees in regions of high sulfur dioxide and ozone concentrations show symptoms that are typical of damage by these pollutants; some trees on soils with known nutrient deficiencies have shown foliar symptoms typical of these deficiencies; but most damaged trees have no identifiable causes.

Airborne chemicals are suspected mainly because no other more plausible explanation has been advanced that can account for the wide variety of symptoms on so many different species of trees and types of forests, growing over so large geographical areas, under so many different soil, site, and elevational conditions.

In the West German province of Baden-Württemberg, a survey of forest damage indicated that the frequency and severity of symptoms was greatest on trees with the greatest exposure to moving air masses. This was shown with regard to predominant wind direction, altitude, position within a stand (edge vs. center, position within the canopy (dominant vs. nondominant trees), type of forest (pure softwood vs. mixed softwood and hardwood), etc. Also, no known fungi or insects, physical climate, or soil-chemical factors were well correlated with damage.

The only direct experimental evidence sug-

gesting which particular airborne chemicals might be inducing some of these symptoms was developed with Norway spruce seedlings. A combination of ozone and acid mist treatments in controlled exposure chambers reproduced the magnesium deficiency symptoms observed in high elevation spruce forests.

4. *High elevation spruce-fir forests in the Appalachian Mountains.* Also entirely circumstantial is the evidence suggesting that airborne chemicals might be involved with the health problems of red spruce and balsam and Fraser firs in the Appalachian Mountains of the eastern United States. The major symptoms of damage on red spruce include dieback of terminal leaders and branches, premature loss of needles, unexplained decreases in diameter growth beginning around 1960, and loss of feeder-root biomass. Unexplained mortality in high elevation red spruce stands has also been reported.

The frequency and severity of these symptoms increases with altitude and thus could be associated with known altitudinal gradients in: a) temperature, b) high winds, c) acidity of precipitation, d) concentrations of ozone and other known pollutants, e) timing of exposure to nutrient-rich and acidic cloud water, and f) accumulation of lead and other toxic metals in forest floor materials. Few, if any, controlled exposure tests have been completed with either red spruce or Fraser fir.

5. *Three cases of decreased growth without visible symptoms.* The recent forest health problems with the least scientific evidence suggesting a link with air pollution include three cases of decreased diameter growth in the absence of other visible symptoms. These three cases include: a) shortleaf and pitch pines in the Pine Barrens region of New Jersey; b) low elevation red spruce forests in New Hampshire, Vermont, New York, and Maine; and c) some naturally regenerated forests of southern pine in Virginia, North and South Carolina, Georgia, and Alabama.

A number of plausible hypotheses involving natural stress factors have been suggested to explain these problems, e.g., increased frequency of droughts, aging of tree populations, increased hardwood competition, and loss of "old field" conditions (decreased fertility of soils after reversion from agriculture). Although it is possible that air-

borne chemicals may have adversely altered the ability of these trees to withstand natural stress factors, no experimental studies have been initiated only recently to test this idea in a scientifically rigorous way.

Conclusions

A great deal is known about the effects of sulfur dioxide and hydrogen fluoride on forests in the vicinity of strong point sources of these pollutants. By comparison, however, very little is known at present about the possibility that regionally dispersed airborne chemicals might be involved in the last three of the five regional changes in forest health and productivity discussed above. Ozone is the only airborne chemical which so far has been rigorously proven to cause regional effects on forests (cases 1 and 2, above). On the basis of general knowledge of the responses of forests to stress, some circumstantial evidence, and a very few controlled exposure tests, however, a consensus of informed judgment is developing which suggests that the following airborne chemicals may be involved. These five airborne chemicals are listed below in order of decreasing probable

importance; the detailed rationale for this ranking is summarized elsewhere:

- ozone;
- acidic or acidifying substances including sulfate, nitrate, chloride, ammonia vapor, and ammonium ion;
- excess nutrient substances—especially greater-than-normal atmospheric deposition of biologically available nitrogen compounds including nitrate and ammonium nitrogen and ammonia and nitric acid vapors;
- toxic metals such as lead, cadmium, mercury, and zinc; and
- growth-altering organic substances such as ethylene, aniline, and dinitrophenols.

Acid deposition in particular and air pollution in general have become major environmental issues in both Europe and North America during the past two decades. Much has been learned already but much more remains to be learned about various aspects of these twin problems.

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Abstract

HENSLEY, D.L. 1986. **Fusilade 2000: toxicity test results.** *Am Nurseryman* 163(10):67.

Selective postemergence herbicides have gained in popularity and use in nursery and landscape markets. One such herbicide, Fusilade (fluazifopbutyl), can be used to selectively remove annual and perennial grasses growing with a large number of landscape species. A new formulation, Fusilade 2000 (fluazifop-P-butyl) has been released. This material contains a greater proportion of the herbicidal isomer of the active ingredient and will replace the familiar 4E formulation. We applied Fusilade 2000 at a pressure of 30 pounds per square inch to 16 woody ornamentals. There was no evidence of foliar damage to any species caused by either solution of Fusilade 2000 two or four weeks after application. Fusilade 2000 appeared to be safe for use on all species studied at the rates tested.