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SCIENCE

Air Pollution and Acid Rain

Research being conducted on air pollution and acid rain is leading to a changing picture of the relative importance of SO_2 and NO_x. Political and regulatory efforts have been focused on sulfur oxides because they produced about twice as much acid as NO_x. However, that emphasis disregards the role of NO_x in the formation of toxic photochemical oxidants. Controlled studies at experimental facilities and observations in the field have identified effects of ozone and NO_x as more damaging to vegetation than SO_2 alone.

In sunlight a complex series of reactions occurs in the troposphere, including photolysis of NO_2 to produce excited atomic oxygen and thence ozone. Additional reactive species formed include hydrogen peroxide, methyl hydroperoxide, peroxyacetic acid, and reactive free radicals, including OH, NO_3, and HO_2. Maxima in the amounts of these species usually occur between 9:00 a.m. and 4:00 p.m. in midsummer. Monitoring has revealed considerable variability in concentrations of the oxidizing pollutants related to abundance of the input substances. Some ozone may be present that originates in the stratosphere.

It has been known that SO_2, NO_x, and O_3 can have toxic effects on plants. In the early days, experiments tended to be performed "scientifically"; that is, plants were exposed in chambers in which the chemicals were tested one at a time. Under those circumstances, it was noted that concentrations of SO_2 and NO_2 greater than ambient were required to produce notable pathology. Indeed, low concentrations of NO_2 were sometimes beneficial (perhaps a fertilizer effect). However, in the real world, pollutants are present together. When experiments were conducted with ambient midday levels of ozone present (for example, 50 to 100 parts per billion), toxicity was noted. When the ozone was supplemented with NO_2, there was usually a substantial additional toxicity attributable to NO_2. Similar results were noted when ozone was supplemented with SO_2.

The deleterious effects of ozone on agricultural crops have been documented and analyzed in a report* issued by the Environmental Protection Agency. It is estimated that a reduction in ambient ozone levels of 25 percent would produce nearly \$2 billion in benefits, while a 25 percent increase in ozone would lead to an additional \$2.3 billion in crop losses.

The photochemical oxidants, particularly OH, have an important role in the oxidation of SO_2 leading to H_2SO_4. In the summer, with abundant OH present, the oxidation proceeds much more rapidly than in winter. Sulfur dioxide emissions in winter and summer are about the same, but the total deposition of sulfate in January and February at stations in northeastern states was found to be a third or less than what it was in midsummer. Deposition of nitrate showed little seasonal effect. Thus, at the crucial time of the spring runoff, the contribution of nitric acid was about equivalent to that of sulfuric acid.

Initiatives to reduce acid rain tend to be centered on the electrical utilities and on their emissions of SO_2. When new coal-fired plants are built, they are required to include facilities for flue gas desulfurization. This adds substantially to the cost of the plant, decreases the efficiency of energy conversion to electricity, and diminishes overall reliability. While the process is effective in capturing SO_2, it is ineffective in removing NO. Any program aimed at reducing acid rain should take into consideration the total air pollution problem, including NO_x. Efforts to reduce SO_2 emissions should be accompanied by a corresponding emphasis on reducing NO_x, whatever the source. For the electrical utilities, this would mean providing more flexibility to use technologies that reduce both SO_2 and NO_x. But in addition, the other large contributors to NO_x, such as motor vehicles, should come under scrutiny.—PHILIP H. ABELSON

*R. M. Adams, S. A. Hamilton, B. A. McCarl, *The Economic Effects of Ozone on Agriculture* (Environmental Research Laboratory, Environmental Protection Agency, Corvallis, Ore. 1984).