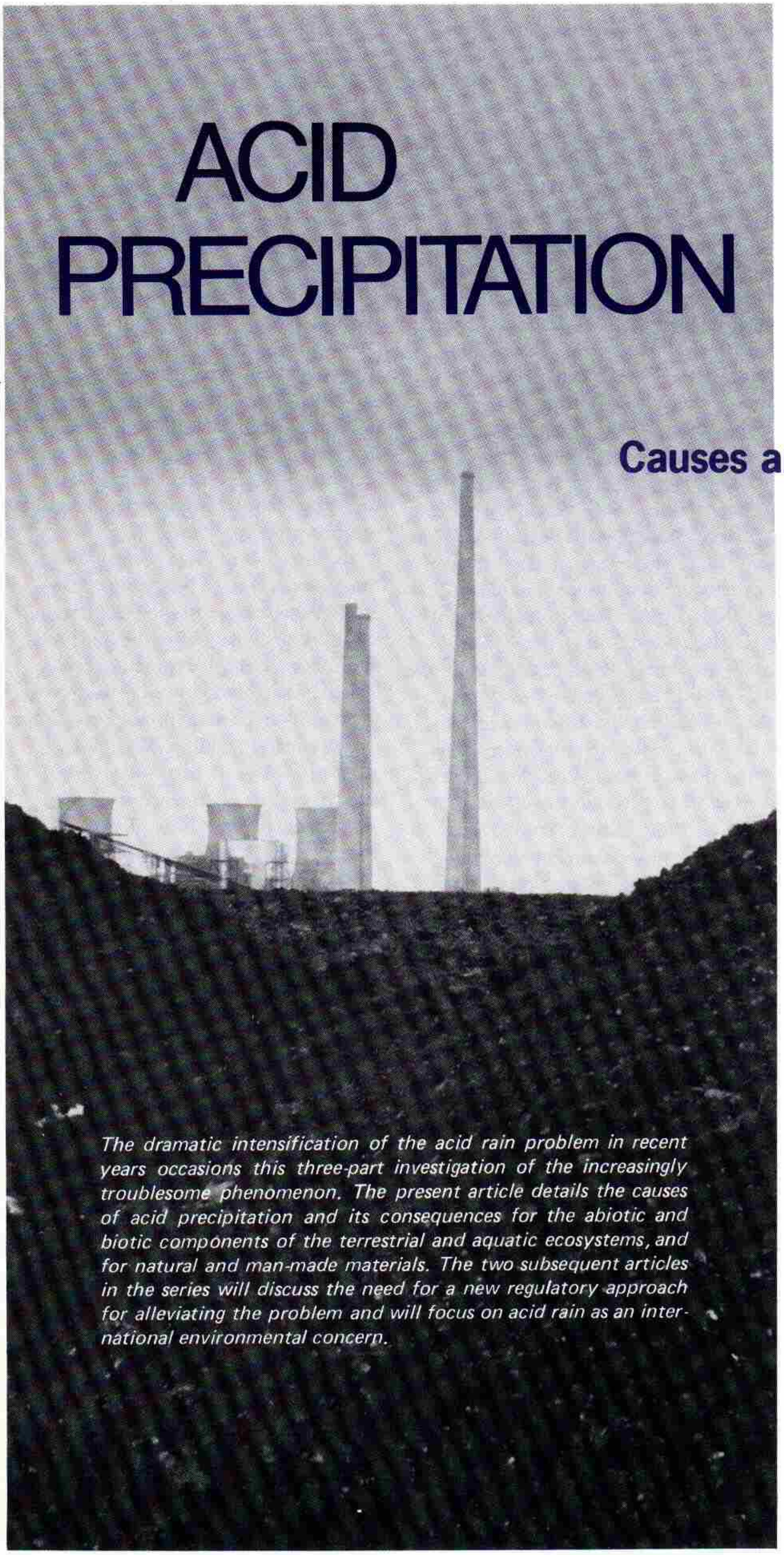

ACID PRECIPITATION

Causes and Consequences

BY HARVEY BABICH,
DEVRA LEE DAVIS,
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The dramatic intensification of the acid rain problem in recent years occasions this three-part investigation of the increasingly troublesome phenomenon. The present article details the causes of acid precipitation and its consequences for the abiotic and biotic components of the terrestrial and aquatic ecosystems, and for natural and man-made materials. The two subsequent articles in the series will discuss the need for a new regulatory approach for alleviating the problem and will focus on acid rain as an international environmental concern.

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THE NOT SO GENTLE RAIN

As a result of the combustion of tremendous quantities of fossil fuels such as coal and oil, the United States annually discharges approximately 50 million metric tons of sulfur and nitrogen oxides into the atmosphere. Through a series of complex chemical reactions, these pollutants may be converted into acids which may return to earth as components of either rain or snow. This acid precipitation, more commonly known as acid rain, may have severe ecological impacts on widespread areas of the environment.

Hundreds of lakes in North America and Scandinavia have become so acidic that they can no longer support fish life. Preliminary research indicates that the yield from agricultural crops can be reduced as a result of both the direct effects of acids on foliage and the indirect effects resulting from the leaching of minerals from soils. The productivity of forests may be similarly affected. In addition, acid deposition is contributing to the destruction of stone monuments and statuary throughout the world.

In recognition of the potential seriousness of the acid rain problem, the President's Second Environmental Message to Congress in August of 1979 called for a minimum $10 million per year research program to be conducted over the next ten years. To implement this program, the Administration created an Acid Rain Coordination Committee comprised of representatives of the Departments of Commerce, Energy, Interior, and State; the Council on Environmental Quality; and the Office of Science and Technology, with the Environmental Protection Agency and the Department of Agriculture as the lead agencies.

PRECIPITATION is a natural cleansing process of the atmosphere which scavenges various atmospheric gases and aerosols and deposits them in terrestrial and aquatic ecosystems. The reaction of rain with alkaline atmospheric gases such as ammonia or some atmospheric particulates such as sea spray, fly ash, and calcareous dust containing calcium carbonate can cause an increase in the acidity (expressed by a decrease in pH value) of atmospheric precipitation.

The pH, the scientific designation to express the extent of acidity or alkalinity of a solution, is determined by a mathematical formula based on a solution's concentration of hydrogen ions (H+). The pH scale ranges from a numerical value of 0 to 14 (see Figure 1 on page 8). A value of pH 1 is very acid (battery acid), pH 7 is neutral (pure water), and pH 13 is very alkaline (lye). Because of the logarithmic nature of the scale, pH 4 is 10 times more acidic than pH 5, and 100 times more acidic than pH 6, and so on. Precipitation is defined as being acidic if the pH is less than 5.6, the lowest pH of normal, unpolluted rain. *Acid precipitation* is rain or snow with pH values of less than 5.6 (the natural pH reduction).

Within the last 20 to 25 years it has become evident that precipitation falling over the eastern United States, eastern Canada, and most of western Europe has become increasingly acidic.[1] In the late 1950s, episodes of highly acidic precipitation were noted in Belgium, the Netherlands, and Luxembourg. By the late 1960s, acid precipitation had extended to Germany, northern France, the eastern British Isles, and southern Scandinavia.[2] Acid precipitation was initially recognized in North America as a result of studies conducted at the Hubbard Brook Experiment Station, New Hampshire. Rain and snow falling at Hubbard Brook from 1963 to 1969 ranged from a low of pH 2.1 to a high of 5, with an average of pH 4.1.[3]

The phenomenon has spread rapidly across the continental United States. In 1955-56, acid precipitation was recorded over 12 states in the northeastern United States. By 1972-1973, acid precipitation had intensified in that area (Figure 2)[4] and extended west and southwest, covering all of eastern North America except for the tip of Florida and northern Canada. In the western United States acid rain particularly affects major urban centers such as Los Angeles, San Francisco, and Seattle,[5] and major mountain areas near the Continental Divide in Colorado.[6]

Causes and Sources

Acid precipitation has been associated with industrial and automotive emissions of sulfur oxides—principally sulfur dioxide (SO_2) and, to a lesser extent, sulfur trioxide (SO_3)—and of nitrogen oxides—principally nitric oxide (NO) and nitrogen dioxide (NO_2). The gaseous sulfur and nitrogen oxides react with atmospheric water and, when oxidized, yield dilute solutions of sulfuric and nitric acids. In some industrialized regions, emissions of gaseous hydrogen chloride (HCl), followed by dissolution in the moisture in the atmosphere to yield hydrochloric acid, also contribute to the formation of acid precipitation.[7] In the northeastern United States, 65 percent of the acidity of precipitation (below pH 5.6) is due to sulfuric acid (H_2SO_4), 30 percent to nitric acid (HNO_3), and 5 percent to hydrochloric acid (HCl).[8] However, this balance is not fixed.

Smelters and coal-fired electric power plants are the primary source of sulfur oxides. The sulfur content of U.S. coals varies: 56 percent of the coal we use has a sulfur content of 1 to 3 percent, while 30 percent of our coal has a sulfur content of more than 3 percent. Eastern coal generally contains higher levels of sulfur than does western coal.

All forms of fossil fuel combustion, particularly that produced by the internal combustion engines of automobiles, emit nitrogen oxides. The rate of nitrogen oxide production increases with the combustion temperature and with the presence of excess air. The nitrogen content of U.S. coals averages 1.4 percent. In residual oils (used primarily for heating homes and other buildings), it is 0.4 percent and in crude oil it is 0.15 percent. Since U.S. coals may also contain as much as 0.65 percent chlorine, coal may also release some hydrogen chloride gas.[9]

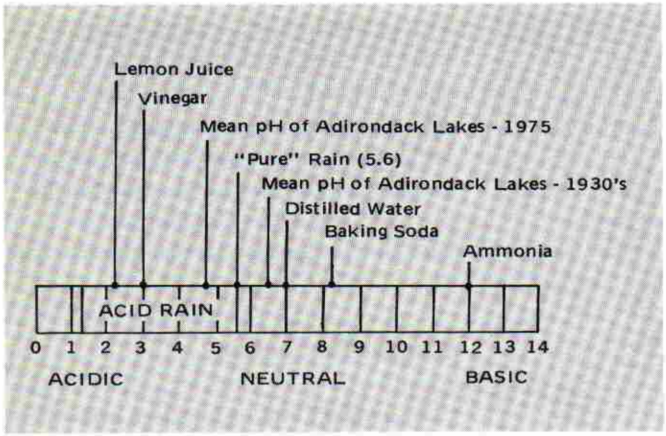


FIGURE 1. The pH scale.

Although sulfate is the principal anion* in acid precipitation over the northeastern United States, the contribution of sulfate to acid precipitation is leveling off, whereas that of nitrate is increasing.[10] This is apparently a reflection of the slowed increase in the nationwide emissions of sulfur oxides due to stringent SO_2 control requirements for major new industrial sources and a simultaneous increase in emissions of nitrogen oxides for which control technologies are less well developed (Table 1).[11]

Long Distance Transport

Some pollutants remain in the atmosphere for relatively long times, during which they are transported (depending on weather patterns) across geographical and political boundaries. This situation creates numerous national and international regulatory problems in that the air pollution standards of one state or country can have an indirect impact on the natural resources of another. The average residence time of sulfur oxides in the atmosphere varies from 1 to 3 days, whereas the average residence time for nitrogen oxides is about 5 days.[12] There are several documented examples of atmospheric transport exceeding 1,000 kilometers before being deposited on the earth's surface.[13]

Fifty-six percent of the sulfur deposited in Sweden and Norway originates outside those countries, primarily in the industrialized regions of northern Europe.[14] Much of the acidity found in the northeastern United States comes from midwestern industrialized regions (Figure 3).[15] Most of the acidity deposited in the La Cloche Mountains in Ontario, Canada, originates in the smelting complex at Sudbury, Ontario, some 65 km away.[16]

The topography of the regions over which air masses move influences pollutants' final deposition. When air masses approach mountain slopes, the cooling effect caused by the upward movement of the air mass enhances the likelihood of precipitation, resulting in a localized deposition of the pollutants. In southern Norway air masses from central Europe and the British Isles travel hundreds of kilometers before their contaminants are removed along the mountainous Norwegian coast.[17]

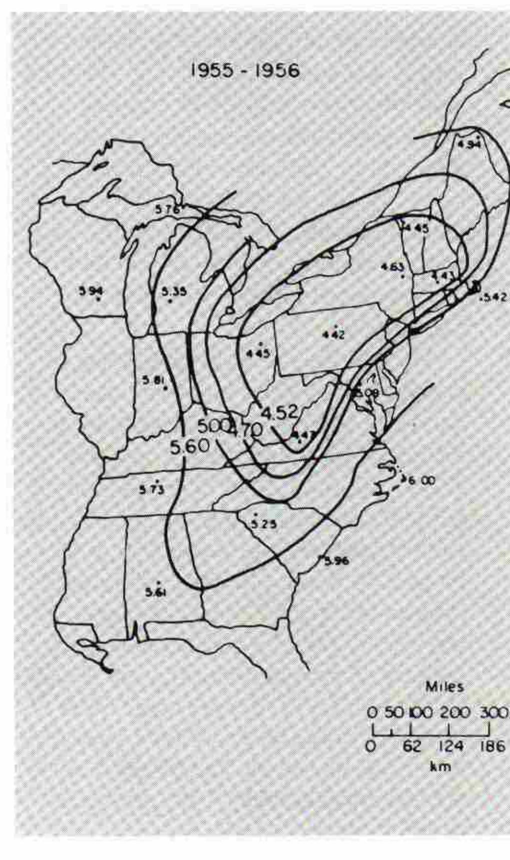
Although large quantities of sulfur oxides and nitrogen oxides have been emitted since the Industrial Revolution (especially in the past 25 years), acid precipitation has only recently been recognized as a problem. Some observers have suggested that control technologies that reduce pollution in the immediate vicinity of the point at which they are emitted actually contribute to the severity of the acid precipitation problem. The use of scrubbers to trap soot particulates and the construction of higher chimney stacks have reduced local pollution problems, but have increased regional transport. Elevated chimney stacks release gaseous pollutants into persistent winds that occur between 150 and 600 meters above ground–promoting their long distance transport. For instance, the copper-nickel smelter in Sudbury, Ontario, has a "superstack" that is more than 400 meters high, and its emissions result in acid precipitation hundreds of kilometers away.[18]

Environmental Impact

Once deposited on the ground or in lakes or streams, acid precipitation may exert a toxic effect on indigenous plants and animals by altering the chemical composition of the environment. The ability of an environment to withstand the impact of acid precipitation is correlated with its capacity to "buffer" or neutralize acids.[19] A buffer maintains the natural pH of a given environment by tying up the excess hydrogen ions introduced by acid rain. Only when the buffer is exhausted will the pH begin to drop.

Before considering the literature on acid precipitation, a word of warning may be pertinent. As with most technical issues, laboratory experiments afford the researcher the utmost control, but questions can be raised about the applicability of the results to the natural environment. For example, many laboratory studies of acid precipitation have

FIGURE 2. Trends in precipitation pH.

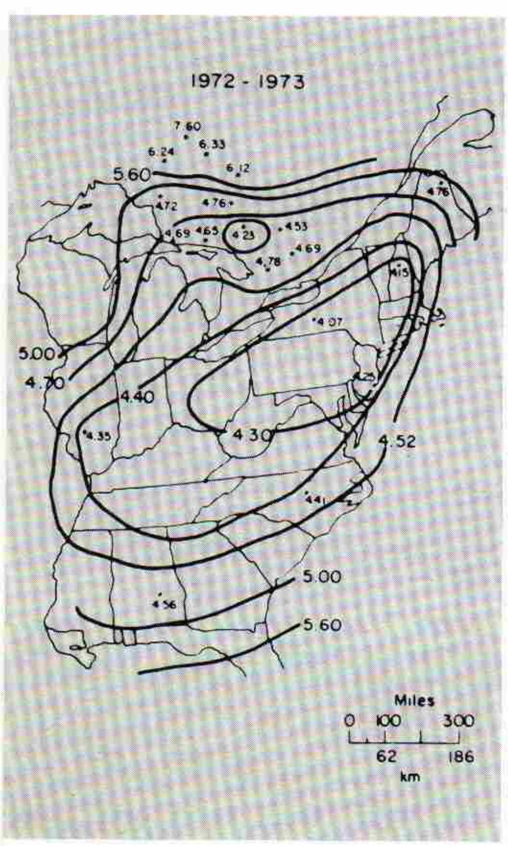


*An *ion* is a charged atom. *Anions* are negatively charged ions and *cations* those which are positively charged.

focused on the excess hydrogen ions and have ignored the excess sulfates, nitrates, and chlorides also present in the rainfall. However, it should be remembered that many studies of environmental contaminants have demonstrated a reciprocal relationship between pollutant concentration and length of exposure time; thus, for example, the chronic effects elicited by exposure for *long* periods of time at pH 4 may be the same as the acute effects elicited by *shorter* exposures at pH 3.

Terrestrial Systems

Abiotic Components. Acid precipitation may meet three possible fates, depending on the specific properties of the environment that receives it: (*1*) The hydrogen ions of the acid precipitation may be neutralized by alkaline salts, such as calcium carbonate. (*2*) The hydrogen ions may exchange with other cations already present on the colloidal clay minerals and humus (*i.e.,* organic matter) in the soil. (*3*) The acid precipitation may leach through the soil and enter the ground or drainage water.[20]



Soil type, then, is a factor in determining an area's susceptibility to acid precipitation. Clay minerals and humus possess surfaces that are predominantly negatively charged, which adsorb positively charged compensating cations such as calcium, magnesium, potassium and sodium. These cations are not permanent components of the surfaces of clays and humus and may be exchanged by other cations such as the hydrogen cations introduced into the soil by acid precipitation. The capability of these colloids to retain exchangeable cations is termed the "cation exchange capacity."[21] The higher the cation exchange capacity of a soil, the more able it is to withstand the detrimental effects of acid precipitation.

Acidic soils, with a low cation exchange capacity, are classified as podzolic soils. Podzolic soils are the most susceptible of all soils to damage by acid precipitation. Much of the Atlantic region of Canada[22] and of the northeastern United States are composed of such soils (Figure 4).

In addition to lowering the pH of some soils, acid precipitation accelerates the leaching of calcium and magnesium,[23] which are alkaline cations and important nutrients for the indigenous biota. Subsequent loss of these elements decreases the fertility and productivity of the soil. For example, soils in southwestern Scandinavia with pH values of less than 3.4 are depleted of alkaline cations.[24]

Heavy metal cations, such as cadmium, nickel, lead, manganese, and mercury, may also be bound to colloidal particles in the soil. Excessive amounts of hydrogen cations introduced into the soil by acid precipitation may exchange for these heavy metal cations, thereby releasing the metals into the soil. Because heavy metals are toxic to plants and animals, even in minute amounts, their mobilization can adversely affect the indigenous biota.[25] Other toxic cations such as aluminum may also be mobilized.[26] Furthermore, these mobilized toxic cations may eventually enter aquatic ecosystems, either by runoff from or movement through soil to underground waters, and damage the biota.

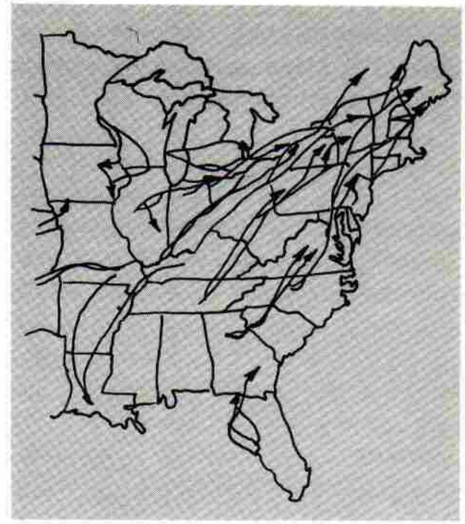


FIGURE 3. Wind trajectories over the eastern United States.

Biotic Components. There have been few studies on the effects of acid precipitation on terrestrial animals. However, it has been suggested that acid precipitation may adversely affect the reproductive success of the terrestrial salamander, *Ambystoma maculatum*, which breeds in temporary ponds formed by accumulation of melted snow and spring rains. Laboratory studies have shown that this organism can tolerate pH values from 6 to 10, but that its greatest hatching success occurs when the acidity is between pH 7 and 9. Complementary studies performed in an acidic vernal pond demonstrated the potential decline of this species, as indicated by reduced hatching success.[27]

A larger number of studies have demonstrated the toxicity of acid precipitation to terrestrial plants. Simulated acid rain (dilute solutions of sulfuric acid), at pH levels less than 3, induced lesions on the foliage of kidney bean, sunflowers,[28] soybean, bracken fern,[29] and species of poplar.[30] Exposure of seedlings of kidney beans to simulated acid rain at pH levels below 3 induced the spotting, or necrosis, of the leaves and reduced the development of the root system, ultimately preventing the plant from attaining normal size.[31] Birch seedlings exposed to an artificial acidified mist, with a pH of 3 or below, developed extensive foliage

Table 1

ESTIMATED NATIONWIDE EMISSIONS OF SULFUR OXIDES (SO_x) AND NITROGEN OXIDES (NO_x)

SOURCE	EMISSIONS (10^6 metric tons)									
	1940		1950		1960		1970		1976	
	SO_x	NO_x	SO_x	NO_x	SO_x	NO_x	SO_x	NO_x	SO_x	NO_x
Transportation	0.6	1.6	0.8	3.0	0.5	4.5	0.7	8.4	0.8	10.1
Stationary fuel combusion	15.1	3.1	16.6	3.9	15.7	4.7	22.3	10.9	21.9	11.8
Industrial processes	3.41	0.1	4.1	0.3	4.8	0.4	5.9	0.6	4.1	0.7
Solid waste	0.0	0.1	0.1	0.2	0.0	0.2	0.1	0.3	0.0	0.1
Miscellaneous	0.4	1.1	0.4	0.7	0.4	0.7	0.1	0.2	0.1	0.3
Total	19.5	6.1	22.0	8.1	21.4	10.5	29.1	20.4	26.9	23.0

SOURCE: Environmental Protection Agency (EPA-450/1-78-003).

A value of zero indicates emissions of less than 50,000 metric tons/years.
Transportation = highway and non-highway vehicles.
Stationary fuel combustion = chemicals, petroleum refining, metals, mineral products, oil and gas production and marketing, and industrial organic solvent use.
Miscellaneous = forest wildfires and managed burning, agricultural burning, coal refuse burning, structural fires, and miscellaneous organic solvent use.

damage as well as decreased growth.[32] It has also been suggested that acid precipitation inhibits the growth of pine and spruce in Swedish soils that are susceptible to damage by acidification.[33] However, decreased tree growth as a result of acid precipitation has not been confirmed in Norway[34] or in the United States.[35]

In addition to adversely affecting plant growth and causing foliage damage, acid precipitation may exert subtle effects on the reproductive potential of plants. Germination of spruce seeds was reduced by 80 percent in soils acidified to pH 3.8 by simulated acid precipitation. During the process of sexual reproduction, the bracken fern forms motile spermatozoids which, in the presence of a thin film of water, swim to the female organs and fertilize the eggs. Laboratory studies have shown that simulated rain reduced spermatozoid motility. For example, after a two-minute exposure, spermatozoid motility was reduced 30, 50 and70 percent at pH 6.0, 5.5, and 5.1, respectively, as compared to control solutions at pH 6.1.[36]

Acid precipitation can also adversely affect the microbiotic components of the soil. Soil microorganisms are involved in many basic ecological processes, such as the decomposition of organic matter, the turnover of nutrients, and the biogeochemical cyclings of chemical elements (for example, the carbon, nitrogen, and sulfur cycles). Soil respiration,[37] an index of overall soil microbial biochemical activity, and the decomposition of leaf-litter[38] were decreased after acidification with simulated acid rain (of pH 2 and pH 5.2, respectively). The decomposition of cellulose also decreased after acidification with simulated acid rain.[39] Inhibition of microbial decomposition of organic matter will eventually decrease the fertility and productivity of that environment.

The nitrogen cycle is particularly sensitive to acid precipitation. Although atmospheric molecular nitrogen is inert for most organisms, it can be utilized by some microorganisms as a source for growth. This process is termed dinitrogen fixation. Simulated acidified rain (pH 4 or less) inhibited dinitrogen fixation by the lichen *Lobaria oregana* (a lichen is a symbiosis between an alga and a fungus)[40] and, at pH 3, by the bacterium *Rhizobium*, which lives symbiotically in the root nodules of kidney beans and soybeans.[41] Nitrification, the microbial conversion of ammonium to nitrate, was also reduced by simulated acid rain (pH 3).[42]

Fungi, in general, are more acid-tolerant than are bacteria, and acidification of soils will retard bacterial growth and enhance fungal growth. Furthermore, simulated acid rain has been shown to alter various bacterium-plant, fungus-plant, and nematode-plant interactions. For example, exposure to simulated acid rain with a pH of 3.2 inhibited the bacterium *Pseudomonas phaseolicola* on kidney beans, the phytopathogenic fungus *Cronartium fusiforme* on willow oak, and the plant-infecting nematode *Meloidogyne hapla* on kidney beans.[43]

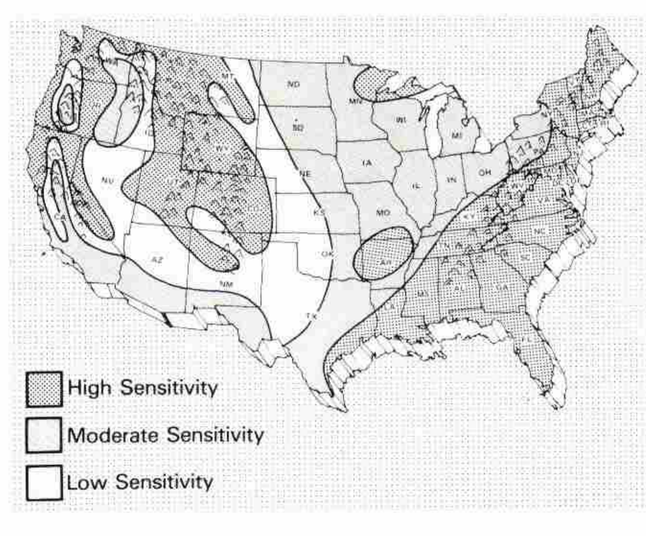


FIGURE 4. Differential sensitivities of U.S. areas to acid precipitation. (Source: EPA)

Unfortunately, few studies have evaluated the possible synergistic or antagonistic interactions between acid precipitation and other pollutants. Lead becomes more toxic to soil fungi as the pH is lowered,[44] whereas cadmium becomes less toxic to soil bacteria and fungi as the pH is lowered.[45] Conversely, soybean plants treated with simulated acid rain accumulated greater quantities of cadmium than did nontreated controls.[46] Emissions of heavy metals and acidic gases (from smelters, for example) need and warrant further study to elucidate the interactions between acid precipitation and heavy metal toxicities.

Aquatic Systems

Abiotic Components. As with terrestrial environments, the buffering capacity of aquatic ecosystems determines their tolerance to acid precipitation. Oceans are highly resistant to acid precipitation because of their high sodium content and the presence of other alkaline cations, such as calcium and magnesium, and the bicarbonate-carbonate system. However, freshwater ecosystems situated on non-calcareous, granite bedrock with a thin covering of organic sediment have a poor buffering capacity and are therefore very susceptible to damage by acid precipitation.[47]

Lakes in the Adirondack Mountains in New York, the Boundary Waters Canoe Area in Voyageurs National Park (BWCA-VNP) in Minnesota,[48] in eastern Canada,[49] and in regions in Scandinavia[50] are highly susceptible to acid precipitation. In the 1930s the majority of lakes in the Adirondack Mountains ranged in pH from 6 to 8, with only 4 percent of the lakes having pH values lower than 5. By 1975, however, the average pH of the lakes was 4.1 to 4.3, with 51 percent of the 217 mountain lakes having pH values below 5.[51] Lakes in the BWCA-VNP area are just beginning to show the effect of acidification resulting from the chronic deposition of acid precipitation.[52] Lakes in the immediate vicinity of the metal smelters at Sudbury, Ontario, have pH values as low as 3.2.[53] Emissions from these smelters have also acidified lakes in the La Cloche Mountains. In 1972, Lumsden Lake in the La Cloche Mountains received in excess of 2,135 kg of atmospheric sulfuric acid, which lowered the pH of the lake from 5.2 to 4.8.[54] In Sweden, more than 10,000 lakes have been acidified to pH 6 or below, with 5,000 lakes having pH values below 5.[55]

The reduction in the pH of lakes induces a variety of other chemical changes. In lakes acidified to pH 5.5 or lower, anionic bicarbonate is chemically transformed to carbonic acid, which is subsequently converted to carbon dioxide. Because of acid precipitation, stream waters in the Hubbard Brook Experiment Station, with an average pH of 5.15, lacked bicarbonate anions and sulfate was the dominant anion. In contrast, bicarbonate is the dominant anion in nonpolluted streams in New England and in most rivers.[56] Furthermore, in aqueous systems with pH values less than 5, colloidal aluminum oxides are rendered soluble, liberating potentially toxic aluminum. Soluble calcium and magnesium cations, mobilized by acid precipitation in terrestrial environments, may also enter aquatic ecosystems through runoff.

Biotic Components. Several studies have noted the disappearance of fish populations in lakes acidified by acid

WHAT CAN WE LEARN FROM THE STONES?

EPA's Office of Research and Development is currently participating in an interagency and international study of the effects of acid precipitation on stone monuments and statuary, and ways to protect against such damage. Because of the many variables associated with material damage to stone, the evaluation of field data and its correlation with atmospheric pollutant levels is very difficult. The ideal subjects for analysis should be uniform materials produced under controlled conditions, placed in a variety of climates and environments over a continuous period of time, and accompanied by accessible, high quality documentation. All of these conditions are met by the marble headstones and markers placed nationwide under the direction of the Veterans Administration (VA).

Since an 1875 Act of Congress, the VA has provided over 2.5 million tombstones to various National Cemeteries. These tombstones have been relatively standardized, being of just a few basic shapes, and are made from stone taken from only three quarries. These nearly ideal conditions offer researchers an excellent opportunity to document the effects of acid precipitation on stone. Approximately one dozen National Cemeteries have been selected in three climate zones for initial study: Appalachian, Far West, and Northeast. Tombstones will be examined for such effects as measurable loss of detail, rounding of edges, and surface erosion to develop quantitative estimates of damage. This damage will then be correlated with data on the stone's history from Veterans Administration records and data on air pollution and meteorological patterns from the National Weather Service.

from EPA Research Summary: Acid Rain (EPA – 600/8-79-028)

Nat'l Park Svc.

Voyageurs National Park, Minnesota, where increased levels of mercury in various lake fish populations may reflect an increased mobilization of mercury due to acid rain.

precipitation. This subtle phenomenon is marked not by major sudden fish kills but by less evident, chronic reproductive failures such as the inhibition of ova release and other developmental interference.[57] The lower pH has also been shown to induce spinal deformities in white suckers.[58] In the BWCA-VNP lakes, increased levels of mercury have been reported in trout, walleyed pike, and northern pike, possibly reflecting an increased mobilization of mercury due to acid precipitation.[59]

Twenty-eight of 67 lakes in the La Cloche Mountain region lost the majority of their fish populations in recent years due to acid precipitation. Smallmouth bass, walleyed pike, lake trout, white sucker, brown bullhead, lake herring, and pumpkinseed sunfish have proved to be the most susceptible species. In the Adirondack Mountains, 90 percent of the lakes acidified to pH 5 and lower are devoid of fish.[60] In Sweden, there are now more than 15,000 fishless lakes due to acid precipitation.[61]

Fish are only one component of the complex food web that exists in freshwater lakes and ponds. A reduction in fish population has two direct ramifications. First of all, a fish population reduction may lead to a proliferation of their prey, such as mosquito larvae, assuming that the prey are acid tolerant. Secondly, the population density of fish predators may be decreased. For example, fish-eating birds, such as mergansers and loons, have migrated from acidified Swedish lakes with reduced fish stocks to lakes with more abundant food.[62] Other aquatic animal species intolerant of acidification include *Daphnia*, a component of the surface zooplankton, and *Gammarus lacusteris*, a bottom dweller, with both species being absent in lakes acidified below pH 6.[63]

The surface phytoplankton, specifically green algae and diatoms, are also sensitive to acidification, with both numbers and species diversity decreasing as the pH of the lakes is lowered below 6. Furthermore, pH values below 6 enhance growth of the moss *Sphagnum*, which usually covers the bottoms of acidified lakes and contributes to the reductions in other forms of plants.[64]

Large accumulations of leaves and other organic debris are frequently evident on the bottom of acidified lakes, indicating a reduction in the microbial decomposition processes in these lakes.[65] Laboratory studies have shown that the decomposition of wilted birch leaves was decreased in lake waters acidified to pH 4.5 to 5.2.[66] Reduced rates of decomposition will lower the fertility of aquatic ecosystems and impair the ability of the affected ecosystems to support an abundant flora and fauna.

Effects on Materials

Most studies on the adverse effects of acid pollutants on materials, such as stone and marble structures and metals, have focused on gaseous sulfur dioxide. Few studies have dealt with acid precipitation directly (see box on p. 11). The deterioration of historic statues and monuments such as the Parthenon in Athens and the Lincoln Memorial in Washington, D.C., has been accelerated by chronic exposure to atmospheric pollutants, including acid precipitation. Acid precipitation acts on stone and marble by dissolving the calcium and magnesium carbonate, thereby creating calcium or magnesium sulfate, both of which are soluble in water. Further precipitation washes off this soluble crust, and slowly but continuously dissolves the structure. Some building stones, such as granite, gneiss, and sandstone, which do not contain calcium or magnesium carbonate are relatively resistant to acid precipitation. However, the concrete mortar binding the building stones is sensitive to decay by acid precipitation.[67]

Acid precipitation also promotes corrosion of metals, particularly iron and iron-containing alloys. Hydrogen ions in the acid precipitation act as acceptors for electrons liberated by the metals. The dissolution of protective coatings on the metal surfaces[68] can also accelerate corrosion. Furthermore, municipal drinking waters, acidified by precipitations, may become contaminated with trace metals mobilized during the corrosion of the water pipes.[69]

Uniqueness of Acid Rain

Although airborne sulfur dioxide and nitrogen oxides are the principal causative agents of acid precipitation, the mode of toxicity of these gases to the biota is distinct from that of acid precipitation. The detrimental effects of gaseous sulfur dioxide are primarily due to the toxicity of its solubility products (for example, bisulfite,[70] sulfurous acid, and hydrogen ions); similarly, the toxicity of nitrogen dioxide is primarily due to its solubility products (for example, nitrite, nitrous acid, nitric acid, and hydrogen ions). In distinction from these, the toxicity of acid precipitation is primarily due to its excessive hydrogen ions,[71] although the excessive sulfate and nitrate anions may also reach toxic levels.

There are other important distinctions between acid precipitation and other atmospheric pollutants, such as sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, peroxyacetyl nitrate, and sulfate aerosols. When these latter substances were recognized as atmospheric contaminants, scientific research was directed to evaluating their modes of direct toxicity to biological systems and their indirect effects in the environment. These studies were needed as there was little or no prior knowledge of the toxicity of these pollutants to the biota.

However, the toxicity of acid precipitation is due largely to its pH effect, and the adverse direct and indirect effects of lowered pH on biological systems and the environment are already well known. For example:

- on the molecular level, reactions in which enzymes are the catalytic agent are pH-dependent, and shifting the pH from the optimal value will reduce or abolish enzymatic activity;
- on the cellular level, lowered pH causes denaturation of proteins, which comprise from 10 to 20 percent of living cells, thus destroying their geometry and hence their biological activity;
- on the organism level, each species has an optimal pH at which it can best maintain and reproduce itself;
- on the population level, acidification of an environment will hinder the establishment and proliferation of acid-sensitive populations; and
- on the environmental chemistry level, acidification is a common laboratory technique used to mobilize cations, including heavy metals, from soils and other materials for subsequent analysis.

Although most atmospheric pollutants are toxic to humans, acid precipitation has not yet been shown to have a direct adverse effect on the health of exposed human beings.[72] The pH of acid precipitation is in the same range as orange juice (i.e., pH 2.6 to 4.4). Humans are usually covered when exposed to acid precipitation and, of greater importance, any exposures are of brief duration, and there is no mechanism for the accumulation of acid rain on an exposed individual.

Prognosis

Acid precipitation could be alleviated by a decrease in fossil fuel combustion. According to Stephen J. Gage, assistant administrator for Research and Development at EPA, "the recently promulgated New Source Performance Standards for fossil fuel power plants will control sulfur oxide emissions from future power plants and, after 1995, begin to effect regional reduction of sulfur oxides and hence acid rain." However, as he acknowledges, this program "does not address continued emissions from existing plants over the next two decades,"[73] and EPA's latest air pollution projections indicate continuing high levels of sulfur dioxide emissions and an increase of approximately 50 percent in nitrogen oxide emissions to the year 2000.[74] In this scenario, then, acid precipitation promises to be an international environmental problem well into the next century.

ACKNOWLEDGMENTS

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current programs to produce fuel from crops are to be minimized, several steps must be taken immediately. The governments launching these programs need to warn food-deficit countries of the potential reduction in exportable food surpluses so that they can adjust their agricultural and population policies accordingly. Secondly, the move toward energy crops reinforces the need for an internationally coordinated effort to arrest the excessive erosion of topsoil. Without such an initiative, the widespread planting of energy crops will accelerate the deterioration of the world's cropland base. Where agricultural fuel programs are launched, priority in the use of fuel should be given to tractors and other farm uses over automobiles. And finally, a global food-price monitoring system that would be sensitive to the impact of alcohol fuel programs is needed. Such a system is essential if political leaders are to assess the worldwide impact of national energy crops initiatives on food prices.

Within the food-exporting countries, the short-run attractions of converting exportable food surpluses into alcohol fuel are undeniable. Whether the longer term political effects will be as attractive is less clear. In a world that no longer has any excess food production capacity, the decision to channel foodstuffs into the production of automotive fuel will inevitably drive food prices upward. For the world's affluent, such rises in food prices may lead to belt-tightening; but for the several hundred million who are already spending most of their meager incomes on food, continually rising food prices will further narrow the thin margin of survival.

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"What we're looking for, Professor, is a cleaner way to pollute the environment."