ACID PRECIPITATION

Implications for forest productivity

The Pennsylvania Slate University and the U.S. Department of Agriculture Cooperating

Acid precipitation, more commonly known as acid rain, has received increased public attention in the last ten years. Acid precipitation probably has existed since the combustion of fossil fuels began over one hundred years ago. It was not until the 1950s, however, that a cause and effect relationship between acid precipitation and ecosystem damage was suggested. Although natural sources of acidity exist In our environment, they generally are included as part of natural nutrient cycles. The addition of acid-causing substances into our environment by humans is not usually incorporated into natural nutrient cycles. Therefore, it is the human contributors of acid precipitation that are of major concern.

Until now, most of the effects of acid precipitation have been associated with aquatic environments, particularly lakes, streams, and their inhabitants. The effects of acid precipitation on fish and other animals living in water are well-documented. Aquatic plants also may be under stress from acid water and the heavy metal toxicity associated with acid water; however, little research in this area has been carried out. The effects of acid precipitation on forests and forest productivity are still areas of uncertainty, although our understanding of this problem is increasing.

Most of the information on forest productivity and acid precipitation comes from West Germany and Scandinavia. Added information comes from the states of Vermont and New Jersey. To date, there has been no comprehensive research effort directed at assessing the impact of acid precipitation on the forests of Pennsylvania. Therefore, any attempts to estimate the potential impact on the forests of the Commonwealth will have to rely on information gathered elsewhere. Having an average pH of 4.0, the precipitation failing on Pennsylvania is the most acidic found in the United States and in the world. With this dubious distinction, it would seem that Pennsylvania would be a likely place to look for acid rain-caused damage to trees.

Documented direct effects of acid precipitation on trees under natural conditions are rare. Although the yellowing of leaves on certain tree species has been attributed to acid precipitation, these effects usually have been demonstrated under carefully controlled laboratory conditions. Laboratory experiments often make use of very acidic water not normally found in nature. This is done to project the long-term effects of acid precipitation. From these experiments it has been found that deciduous leaves appear to be more sensitive to acid rain damage than coniferous leaves. The most vulnerable stage of plant development appears to be just prior to maximum leaf enlargement.

The greatest effect on leaves still attached to the tree is the direct leaching of nutrients from the leaf surfaces. Some of the precipitation falling through a forest canopy will flow over or be held by foliage, allowing nutrients to be dissolved from the leaves and suspended in water droplets. These nutrient-carrying droplets eventually fall to the forest floor. The nutrients most readily affected are calcium, magnesium, and, to a lesser extent, potassium. If these nutrients remain dissolved in water droplets when entering the soil and do not become attached to soil particles or absorbed by roots, they can be carried beneath the rooting zone where they are unavailable co trees.

Acid precipitation also has been noted to alter the species composition and numbers of microorganisms essential to forest litter (leaves, stems, and fruits) decomposition. Consequently, the rate of litter decomposition normally is reduced and thereby ties up nutrients necessary for plane growth and development. The natural cycles of these nutrients, which have been established over thousands of years, are disrupted. This forces forest ecosystems to adjust to these altered cycles and to fit the reduced supply of nutrients available from decomposition sources. How crucial these changes are to the nutrient cycles and how quickly a-forest can adjust to them is not known. If the adjustment is slow, long term, subtle changes in forest productivity may result.

Along with nutrients being lost through direct leaching from leaves and the immobilization of nutrients in forest litter, nutrients can be lost from the soil. Acid water flowing through the soil can exchange acidic hydrogen ions for essential plant nutrient ions such as calcium, magnesium, and potassium. If these nutrients migrate beneath the rooting zone, they become unavailable to tree roots.

A third effect on the leaves of some trees is the damage or complete breakdown of the waxy outer covering of leaves (cutin). Loss of cutin could mean unusually high water loss from the tree. During droughts or on marginal sites with a typically low water supply such as ridge tops in Pennsylvania, an increased water loss could translate into reduced vigor for some trees. Cutin also is important to the mechanical support of the leaves and prevents leaves from drooping unnaturally. The prevention or reduction of chemicals entering the leaf is another important function of cutin. Leaves that lose their waxy coating are more likely to be damaged by subsequent acid precipitation or acid-forming particles and gases in the air. Seed germination as well as seedling emergence and establishment are early growth phases chat also may be affected by acid precipitation. Each tree species acts independently and as of yet no generalizations can be made. For Instance, seed germination for yellow birch and red maple is inhibited, but sugar maple seed is unaffected when exposed to a water treatment of pH 3.0 or less. Some conifers such as white pine and white spruce actually have a better germination percentage when seed is exposed to a pH 3.0 treatment. There is no effect on eastern hemlock.

In nature, conifers generally grow on more acidic soils than hardwoods and the acidity of their decomposing litter perpetuates the acid nature of the soil beneath them. Conifers, therefore, would be expected to tolerate more acid conditions. The best documented effects on forest productivity and vigor, however, concerns conifer species: the high mountain red spruce of Vermont, the pine barrens of New Jersey, the Norway spruce stands in Scandinavia, and the spruce and beech forest of West Germany. The most extensive research has been carried out in West Germany where the widespread death of spruce trees concerns each age class and regeneration is drastically reduced or nonexistent. Researchers blame heavy metals, especially aluminum and manganese, for causing these problems. At present, much more is known about how aluminum affects trees than about the role of manganese.

Mycorrhizae are soil fungi that live on or in the roots of most tree species. The presence of mycorrhizae is essential to successful growth of many species, particularly on drought and nutrient-poor sites. For example, pines typically grow on nutrient-poor sites and normally do not grow without the assistance of mycorrhizae. A major benefit of mycorrhizae to forest trees is that they are highly efficient accumulators of nutrient ions and water. The ability of mycorrhizae to supply nitrogen to trees from nitrogen-poor soils is one example. Mycorrhizae also are important in nutrient cycling. They^ absorb soil nutrients and serve as reservoirs for nutrients that might otherwise be leached from the soil. Research has shown that pines infected with a certain mycorrhizal fungus may be expected to exhibit increased tolerance to extremes of soil acidity as well as high sulfur and aluminum levels associated with strip-mined land. High acidity and levels of sulfur and aluminum also are associated with acid precipitation. Trees that initially show a tolerance for these conditions likely will decline in vigor as their mycorrhizae are destroyed by acidic conditions.

When acid precipitation moves through the soil, chemical processes take place which allow aluminum to break away from tightly held sites on particles of soil clay. The aluminum is then dissolved in the soil water. If the soil water has a pH less than about 5.4, the aluminum in solution is generally toxic. As German scientists describe it, aluminum under these conditions destroys or at least inhibits the function of the fungal mycorrhizae and small root hairs of the trees.

Aluminum toxicity is believed to be a primary factor in limiting plant root development, i.e., depth and branching, in many acidic subsoils of the southeastern United States. Disruption of the mycorrhizae and small roots seriously affects the ability of trees to take in nutrients and water, and may even affect the trees' defense against natural pests and diseases. With this deterioration in root function, the vigor of the trees is reduced and may cause lower productivity or death in the most severe instances. For example, oak trees subjected to gypsy moth caterpillars or drought may experience greater mortality than expected if also under stress from acid precipitation.

It also has been noted that the type of precipitation is important in determining effects on trees. In the Green Mountains of Vermont, there appears to be a very good direct relationship between the occurrence of fog and the affected trees. Fog, as a form of precipitation can be many times more acidic than rain or snow. A concentrating effect in fog and a pH of 3.5 to 3.7 for acid fog is not uncommon in the Green Mountains. Due to this high acidity and the manner chat fog encompasses and condenses on vegetation rather than simply passing through it, there is a high potential for serious acidic effects from acid fog.

While the mountains of Pennsylvania do not reach the 4,000 foot elevation attained by the Vermont mountains, they are subjected to the occurrence of fog for many days throughout the year. Therefore, it is possible that those trees in Pennsylvania encountering fog on a regular basis may be adversely affected by acidic conditions. It is not known how acidic the fog is in these areas or if it is affecting the predominantly deciduous forest in any way. The possibility exists, however, that the forests in these areas are under the same stresses associated with the dead and dying trees observed in Vermont and other places.

While acid precipitation has existed for many years, and its presence and the damage it does sometimes are very subtle, the effects of acid precipitation on forest productivity remain undetermined in Pennsylvania. If forest productivity is indeed being decreased due to acid precipitation, it could mean a significant loss in revenue from the several millions of dollars generated annually through forestry-related activities in the Commonwealth.

This material was prepared by Robert T. Liebfried, Research Assistant, Institute for Research on Land and Water Resources at The Pennsylvania State University.