ELEMENTAL CYCLING RESPONSE OF AN ADIRONDACK SUBALPINE SPRUCE-FIR FOREST TO ATMOSPHERIC AND ENVIRONMENTAL CHANGE

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Abstract: Patterns and trends in forest elemental cycling can become more apparent in the presence of atmospheric perturbations. High-elevation forests of the northeastern United States have received large amounts of atmospheric deposition of pollutants, which have altered natural elemental cycling and retention rates in a variety of ways. This study examined atmospheric deposition of nitrogen, sulfur and base cations, and their interactions in a high-elevation forest on Whiteface Mountain, New York. Eight years of elemental cycling data (1986-1993) have shown that at our main study site (1050-m elevation), atmospheric deposition of N was approximately 16.7 kg N ha^{-1} yr^{-1}, with 32 percent contributed by cloud water. Atmospheric deposition of S was 16.3 kg S ha^{-1} yr^{-1}, with 37 percent contributed by cloud water. Total atmospheric inputs of nitrogen and sulfur to the forest canopy increased by a factor of four and five, respectively, over the elevational range of 600 to 1275 m, largely due to the increased importance of cloud water deposition at high elevations. At 1050-m elevation, analyses of total ecosystem inventories and cycling revealed that nitrogen and potassium are conserved or retained in the ecosystem while sulfur, calcium and magnesium show losses in a relatively undisturbed spruce-fir-birch ecosystem.

INTRODUCTION

High elevation forests in the northeastern USA currently receive higher pollutant deposition inputs than most other locations in the country (Lovett 1994). Deposition rates were much lower earlier in this century, increased in the 1950s through 1980s, and have begun to decrease over the last ten years or so, depending on the element (NAS, 1986; Hedin et al. 1994; Miller and Friedland 1994). Atmospheric deposition has been shown and has been hypothesized to cause a variety of direct and indirect effects on forested ecosystems (Taylor et al. 1994). Given that elemental deposition rates will continue to change over the coming decades (EPA 1995), it is important to understand the role of atmospheric deposition in elemental cycling in forested ecosystems. A high-elevation site in the Adirondacks is an ideal location to study these projected changes and the potential effects of such changes because these types of sites: (1) receive relatively large pollutant inputs (Miller et al. 1993b); (2) already show some signs of assimilating atmospheric pollutants (Friedland et al. 1991; McNulty et al. 1991); and (3) have undergone significant red spruce decline, partly as a result of air pollution (Eagar and Adams 1992) which has changed the composition of the forest (Scott et al. 1984; Friedland 1989; Battles et al. 1992).

In order to ascertain the effects of atmospheric deposition of pollutants on a high-elevation forested ecosystem, we have established atmospheric deposition and nutrient cycling monitoring plots on Whiteface Mountain, New York. These include two towers for atmospheric measurements, four 0.1 hectare permanent plots and two adjacent monitoring plots where litterfall, throughfall and soil water collectors have been installed. This project is the core effort of a series of projects funded by the USDA Forest Service Northern Global Change Research Program, NSF and the Andrew W. Mellon Foundation. As such, a primary objective of this project has been to provide a comprehensive evaluation of atmospheric deposition and nutrient cycling in high-elevation forests that can serve as a foundation for other process-level research, including branch and tree fertilizations.

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RESULTS AND DISCUSSION

Ecosystem Mass Balance

An eight-year average of wet (a combination of rain, snow and cloud water) and dry input delivered to the forest illustrates that input is dominated by hydrogen ion, ammonium, nitrate and sulfate (Fig.1). This is similar to deposition in many forests in the Northeast, but total deposition amounts are higher here because the site is at a higher elevation and is immersed in clouds as much as 10 percent of the year (Miller et al. 1993c). No element shows constant input and output during the eight years of measurements (Fig.1). Calcium and magnesium inputs are fairly constant during the eight years of our study, although there is a long-term trend of decreasing calcium inputs in the Northeast (Hedin et al. 1994). Hydrogen ion and ammonium outputs are nearly constant during the study, and ammonium outputs are virtually zero. Nitrate output varies from year to year but is definitely greater than zero. High ammonium output is thought to be one indication of the later stages of excess nitrogen storage in an ecosystem, also called nitrogen saturation (Aber et al. 1989). Apparently, this site is not in the later stages of nitrogen saturation. But the continual loss of nitrate suggests that the site might be in early stages of nitrogen saturation (Aber et al. 1989). Hedin et al. (1995) suggest that the loss of nitrate is an indicator of a polluted system.

Elements can be grouped into three categories based on their behavior: (1) sulfate and potassium outputs appear to be sensitive to inputs of sulfate and potassium, respectively; (2) hydrogen, ammonium and nitrate outputs appear to be insensitive to inputs of these same ions; and (3) the outputs of calcium and sulfate appear to be linked to one another (Fig. 1). These patterns suggest that the outputs of sulfate and potassium are in part regulated by inputs of those ions and of hydrogen ion. Both calcium and sulfate outputs are greatest in the 1989 water year, when water deposition is approximately 60 percent greater than any other year of the study and hydrogen ion input is greatest. Apparently, leaching of calcium and sulfate pools is at least partially dependent on water flow. This pattern of increased leaching with increased water flow is seen for nitrate but not sulfate in streams in the Catskills in 1989 (Murdoch and Stoddard 1992), and suggests there is a relatively labile pool of exchangeable sulfate and calcium (e.g. Johnson et al. 1991). Outputs of ammonium and nitrate are apparently insensitive to the size of the input presumably because they are in relatively high biological demand. However, nitrate output was high in at least one year, 1987 (Fig. 1B), and is significantly higher during the non growing season (data not shown), suggesting that plants are using most of the nitrogen available during the growing season but that atmospheric deposition provides excess nitrate to the system at other times of the year.

In a previous study (Johnson et al. 1994), we presented hydrogen ion and calcium budgets for this forest and suggested that current calcium loss rates are higher than historical loss rates. However, the same article suggests that hydrogen ion accumulation will be offset by mineral soil weathering (which consumes hydrogen ion). The only pool that is questionable in terms of sustainability is the forest floor calcium pool.

In Miller et al. (1993a), we show that as much as 60 percent of the forest floor calcium pool is derived from atmospheric calcium. Given that calcium outputs appear to be influenced by inputs of hydrogen and outputs of sulfate (Fig. 1A,E,G), and since calcium deposition to the northeast has been decreasing (Hedin et al. 1994), it is reasonable to be concerned about calcium limitations in the future. This situation could be exacerbated by increased nitrogen deposition, which may occur; and it could be partially ameliorated by reductions in sulfur deposition. The effect of increased temperature is much more difficult to predict. Thus, the specific nature of the environmental change over the next few decades will be critical in determining the future health of high elevation spruce-fir-birch forests.

Atmospheric Deposition

Inputs of elements such as sulfur and nitrogen increase by a factor of four and five, respectively, over the elevational range of 600 to 1275 m (Fig. 2; for nitrogen, data not shown). Steep gradients in wind speed and cloud immersions contribute to a nearly exponential increase in ion deposition by cloud water interception. Deposition rates are for simulations based on wind speeds representative of topographically sheltered inter-montane areas below 1000-m elevation (Miller et al. 1993b). Atmospheric inputs can vary significantly from year to year (Fig. 1) in forests subject to significant cloud water deposition; therefore, atmospheric influences on the nutrient cycling can be dynamic as well as chronic.

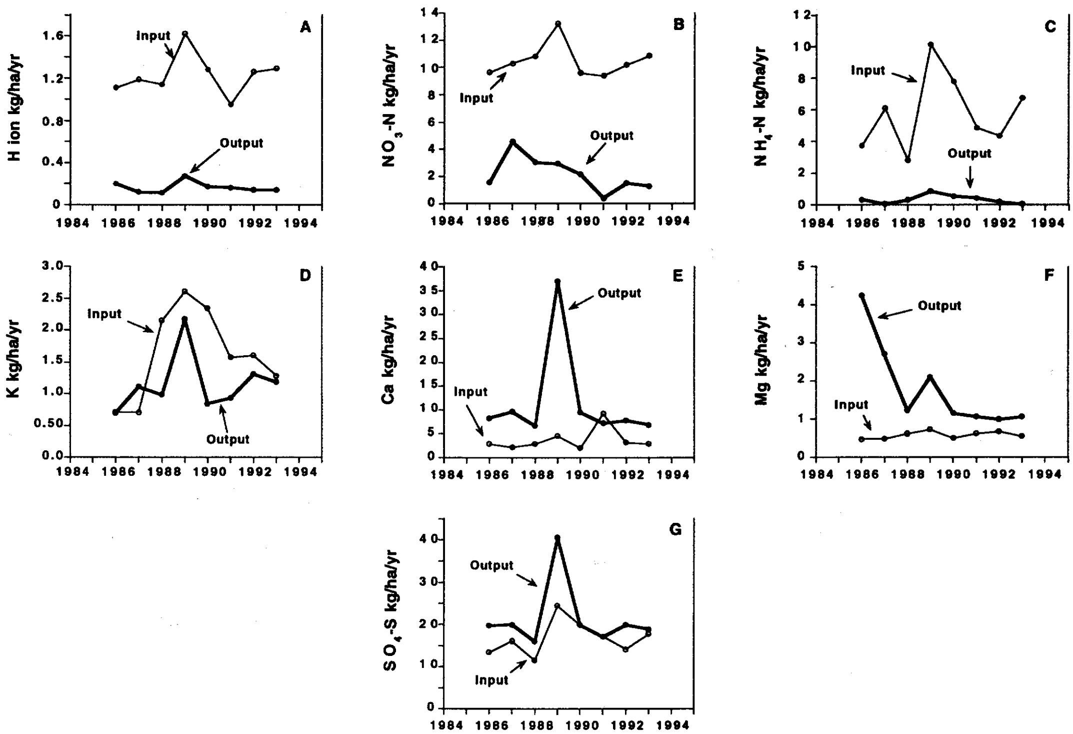

Fig. 1. Yearly mean inputs (precipitation + cloud water + dry deposition) and outputs (Bw horizon soil water) from 1025-m elevation on Whiteface Mountain, New York between 1986 and 1993. A given year (i.e., 1986) represents Water Year 1986 (June 1, 1986-May 31, 1987). Source: A.J. Friedland and E.K. Miller, unpublished data.

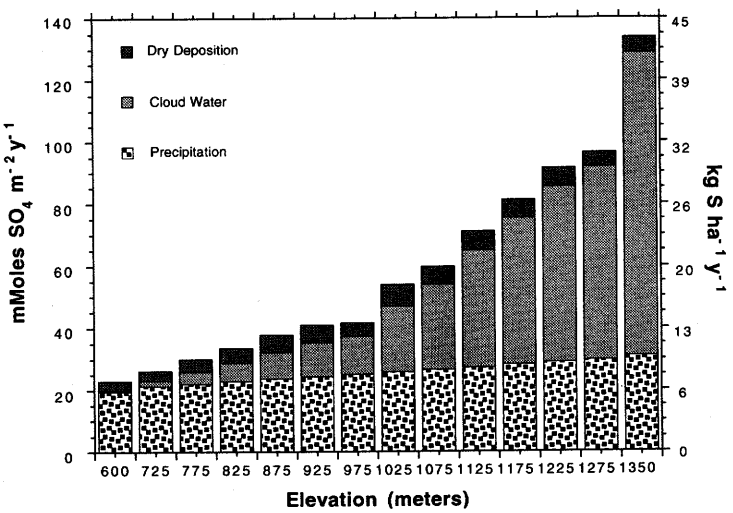

Fig. 2. Model estimates of the total annual deposition of sulfur to the forest canopy on Whiteface Mt., NY. Deposition rates are for model simulations based on wind speeds representative of topographically sheltered inter-montane areas below 1000 m. Estimates of deposition rates to low elevation forests on more exposed mountain slopes and in the low elevation terrain surrounding the high peak region are indicated by the open bars. Source: Miller et al. 1993b.

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