From: EFFECTS OF ACID PRECIPITATION OF
TERRESTRIAL ECOSYSTEMS
Edited by T.C. Hutchinson and M. Havas
(Plenum Publishing Corporation, 1980)

PREDICTING POTENTIAL IMPACTS OF ACID RAIN ON ELEMENTAL CYCLING IN A SOUTHERN APPALACHIAN DECIDUOUS FOREST AT COWEETA

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INTRODUCTION

Acidification of rain fall in Europe[1,2] and in the eastern United States has been reported.[3,4,5] Reports of damage to individual organisms and to aquatic ecosystems, though few, are growing in number. The ability of hydrogen ions to displace biologically essential cations from exchange sites in soil and from plant tissues is especially significant. Chronic exposure of ecosystems to acid rain has a potential to disrupt the cycling of plant nutrients upon which continued plant productivity in part depends. Understanding the magnitude and consequences of this disruptive effect is critical to the development of alternative ecosystem management strategies. The problem is to predict ecosystem responses to acid rain so that costs and benefits of alternative management plans can be evaluated. Investigations presently underway are designed to provide preliminary predictions for southeastern deciduous forests. Work is being conducted on experimental watersheds at the Coweeta Hydrologic Laboratory, operated by the U.S. Forest Service, Franklin, North Carolina, USA.[6] Here we briefly describe the main features of our investigations for the interests of others planning related investigations in other ecosystems.

The plant leaf, the plant root, and the soil seem likely to be important components determining ecosystem responses to differing regimes of acid precipitation. Leaves are the most physiologically active of the plant organs exposed directly to acid rain. The buffering capacity of the soil is likely to control nutrient losses from systems by leaching, and also to control the chemical environment in which both nutrient uptake by roots and nutrient release by decomposed organisms occurs. The nutrient processing responses of leaves, roots, and soil to differing regimes of acid precipitation are being experimentally characterized. Recharge of soil exchange sites following cessation of acid rain inputs is also being characterized. These nutrient-processing responses will eventually be incorporated into existing ecosystem-level models in order to simulate nutrient cycling and production processes under acid rain regimes differing in intensity and in duration. System behavior following cessation of acid rain inputs can also be simulated. This combined experimental-simulation approach can provide preliminary answers to potentially critical questions concerning responses of terrestrial ecosystems to acid rain.

EXPERIMENTAL INVESTIGATIONS

Work in progress is designed to test the following null hypotheses: 1) losses of ions from leaves of dominant tree species are independent of rainfall pH over the range from pH 5.5 to 2.5; 2) if rainfall pH significantly affects quantities of elements leached per unit leaf area, leaching rates are identical for dominant tree species; 3) kinetics of ion uptake by roots of dominant tree species are independent of hydrogen ion activity over the range from pH 5.5 to 3.5; 4) if kinetics of ion uptake by roots are affected by pH, roots of all dominant species respond in the same manner; 5) nutrient losses from forest soil are independent of the pH of extraction solutions over the range of pH 5.5 to 3.5; and 6) if significant nutrient losses occur, the curves characterizing nutrient recharge of soil exchange sites are simply the reciporcals of the cumulative leaching curves. In other words, there is no hysteresis.

Dominant tree species collectively comprising more than 50% of the basal area on the watershed[7] are *Carya glabra*, *Quercus coccinea*, *Quercus prinus*, *Cornus florida*, *Liriodendron tulipifera*, and *Acer rubra.* Because of low transplant success, *Carya illinoiensis* and *Quercus rubra* have been substituted for the first two species.

Leaves of seedlings of dominant species are being leached with simulated acid rain for 1 hour per week at the average rainfall rate for the watershed of 0.89 cm/hr.[8] Simulated acid rain mimics rain chemistry reported from Coweeta,[9] and is acidified to pH 5.5, 4.5, 3.5 and 2.5 with reagent acids in ratios of SO_4:NO_3:Cl of 10:7:1 following the acid rain chemistry reported from New York State.[10]

Soil leaching studies have been performed on aliquots of a statistically representative composite sample from the forested watershed. Leaching solutions contained a salt component and an acid component, each at 3 levels. Salt concentrations were based on elemental contents of soil solutions sampled with zero tension lysimeters[11] beneath the litter layer in the watershed. Salt levels 10 and 100 times greater were also used in case the artificial acid rain increased the elemental contents of leaf and litter leachates by large factors, thereby increasing concentrations of counter ions in the soil solution. These salt solutions were acidified just as were the leaf leaching solutions, but only to pH 5.5, 4.5 and 3.5, resulting in 9 different pH-salt combinations. To condense time, aliquots of sieved soil, corresponding to the amount in a core 1 cm in cross-sectional area and 10 cm deep were equilibrated with the average rainfall of 215 cm per year for 20 hours on a reciprocating shaker. Samples were centrifuged and the supernate decanted for chemical analysis. New annual increments of artificial acid rain were then equilibrated with the soil. The process was repeated 10 times on duplicate samples.

Quantification of effects of H^+ on elemental uptake by tree roots has proven to be the most difficult part of the investigation, with attempts being made using isolated roots[12] and growing seedlings potted in sand and irrigated with experimental solutions.

Solution samples from leaf leaching, soil leaching, and root uptake experiments are analyzed for Na, K, Mg, Ca, NH_4, SO_4, NO_3, and Cl. Data will be subjected to appropriate analysis of variance procedures to test the 6 null hypotheses. Where acid treatments significantly affect movements of NH_4, NO_3, K and Ca, these responses will be incorporated into the ecosystem simulation models. Modeling efforts for other elements have not yet been initiated.

MODELING AND SIMULATION

Current understanding of element cycling processes in southern Appalachian deciduous forests have been synthesized into compartmental models for N[13] and for K and Ca.[14] Refinements of all models are currently being developed. These elemental cycling models will be combined in the future to produce an integrated model accounting for both production and elemental cycling, again with major emphasis on the elements K, Ca and N.

Figure 1 illustrates the types of predictions for which these simulation models have been used to date. The nitrogen model has been used to predict consequences of various types of forest harvesting on the nitrogen cycle and on the long-term sustainable productivity of southeastern forests receiving increasing demands for wood products.[15,16] Simulations were performed for deciduous

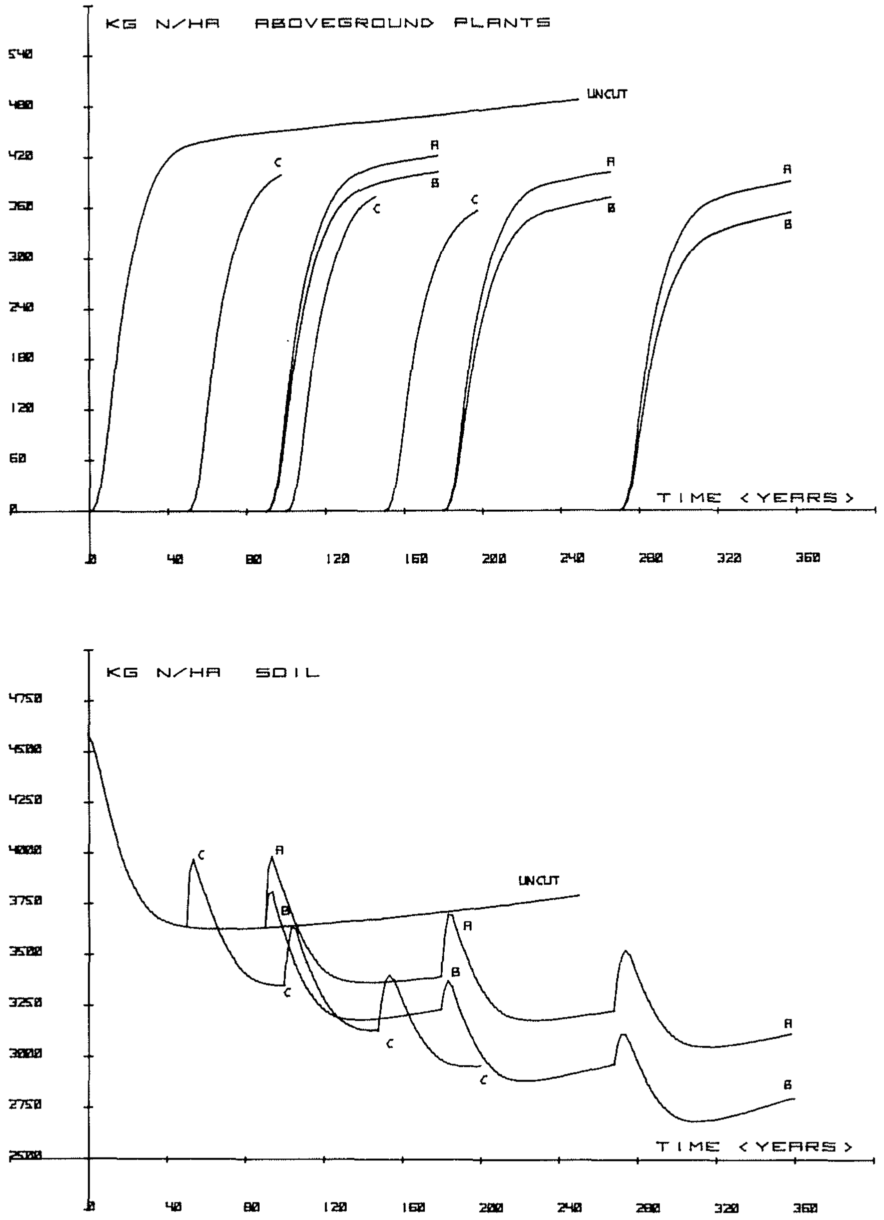

Figure 1. Simulated changes in nitrogen in all above ground plants and total nitrogen in soil of a southern Appalachian deciduous forest subject to three types of forest harvesting: A. merchantable timber removal, 90 yr rotation length; B. complete tree harvest, 90 yr rotation length; C. merchantable timber removal, 50 yr rotation length.

forests based on data from Coweeta and also for a loblolly pine stand in the Duke forest based on published literature data. Various types and frequencies of cuts were simulated for both forest types. Such simulation results (Fig. 1) clearly suggest that increasing the amount of forest biomass removed in harvesting operations or shortening the period between successive harvests, may prove especially damaging to the ability of southeastern forests to sustain high levels of productivity over long time periods, as well as to the functioning of the forest ecosystem itself.

Integration of our experimental work and the continually evolving ecosystem models will make possible such predictive simulations of potential long-term responses of southeastern forests to acid rain regimes differing in intensity and in duration, as well as of ecosystem recovery following cessation of low pH rainfall. It is clear that acid rainfall is an ecosystem level problem and that a full understanding of its potential impact can best be gained by appropriate combination of experimental and modeling approaches such as those described here.

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