B. Abstract

Assessing the Sensitivity of New York Forests to Calcium Depletion from Acid Rain

The degree to which acid rain threatens forest health and productivity depends in part on the ability of soils to supply calcium and other base cations for forest growth. Predictions of Ca depletion have been based on the assumption that only the salt-exchangeable Ca pool is available to plants; the weathering of Ca from parent materials has been believed to be too slow to play a role in mediating the acidifying effects of air pollution on soils. Because of these assumptions, the role of readily weathered Ca-bearing trace minerals, such as apatite and calcite, have been overlooked in assessments of Ca depletion from acid rain. The first objective of the proposed work is to describe the distribution of Ca-bearing minerals across soil parent materials in New York State. The second objective is to assess the relative ability of important tree species to access Ca from various sources, including trace minerals. Information about the distribution of Ca sources and the ability of tree species to obtain Ca is essential to predicting the sensitivity of forests across New York State to Ca depletion, with implications for sustainable forest management and air pollution policy.

C. Program Interest Area to be Addressed

The proposed project will address the *Atmospheric Deposition of Sulfur, Nitrogen, and Mercury, and Ecosystem Response*, specifically to *(6) Assess the effects of deposition on forest health in geologically sensitive areas of New York State*.

Up to this point, geologically sensitive areas of New York State have been defined as those in which surface waters have been acidified (e.g., April et al., 1986). We contend that this definition may be incomplete, at least from the point of view of protecting and managing forest health. Areas with few carbonate rocks, such as the Adirondacks and Hudson Highlands, may indeed be most susceptible to acidification of surface waters, and the low buffering capacity of soils may explain the phenomenon of dead lakes (Reuss and Johnson, 1986). But the susceptibility of forest soils to Ca depletion may also depend on the presence of trace minerals such as apatite. At the Hubbard Brook Experimental Forest in New Hampshire, our budgetary calculations revealed that 20% of the Ca now cycling through forest biomass was originally weathered from apatite (Nezat et al., 2004). The focus on feldspars and other Ca-bearing silicate rocks in calculating weathering rates of Ca (Bailey et al., 1986; Likens et al., 1998) is not surprising, given the dominance of silicate minerals in the parent material. But the omission of non-silicate minerals as a Ca source may have seriously overestimated the threat to forest health from acid rain.

Establishing the importance of Ca-bearing minerals in parent materials across New York State, in combination with assessing the ability of various commercially and socially important tree species to obtain Ca from sources such as apatite, will enable us to better predict the susceptibility of forests to Ca limitation across a geologically and ecologically varied landscape.

D. Usefulness and Value of Project Results

There has long been concern that base cations are being depleted from forest soils in the northeastern United States as a result of acid rain (Shortle and Bondietti, 1992; Likens et al., 1998). These losses from soil were predicted to be compounded by timber harvesting and the associated loss of nutrients, with Ca the element most likely to become limiting (Federer et al., 1989). Retrospective studies have reported dramatic declines in pools of exchangeable base cations (Johnson et al., 1994; Knoepp and Swank, 1994; Huntington et al., 2000). The loss of cations in general and Ca in particular over past decades is thought to have adversely affected forest productivity and health in eastern North America (Shortle and Bondietti, 1992) and Europe (Ulrich et al., 1980; Graveland et al., 1994). Clearly, assessing the importance of regulating pollutants associated with the generation of electricity depends on accurate assessments of the threat posed to ecosystems by cation depletion.

The plant-available pool of soil Ca has commonly been equated with the salt-exchangeable fraction (NH_4Cl), and the non-exchangeable pool has been assumed to be dominated by slowly weathered silicate minerals (Bailey et al., 1996; Likens et al., 1998). However, an acid leach of soils from a 65-90 year-old northern hardwood stand at the Hubbard Brook Experimental Forest removed a relatively large pool of Ca (65 g Ca/m2 in E and B horizons and 6 g Ca/ m^2 per cm of depth in the C horizon) (Hamburg et al., 2003). The :P and Ca:Sr ratios suggest that this treatment dissolved the non-silicate mineral apatite ($Ca_5(PO_4)_3OH$), which is in lower abundance but are much more rapidly weathered than silicate minerals. Both apatite and calcite ($CaCO_3$), another Ca-bearing trace mineral, are ubiquitous as small inclusions in the silicate minerals of the soil parent material, as revealed by cathodoluminescence imaging of soil thin sections. The very high Ca/Sr ratio of this extract is quite characteristic of these non-silicate minerals, and will be useful for distinguishing the source pools of Ca to various tree species.

Project Goals and Objectives

The overall goal of our project is to better understand the sensitivity of forests across New York State to Ca depletion. Both the distribution of Ca sources and the ability of tree species to obtain Ca from these sources are essential to predicting the future health of the forest resource and the value of environmental controls on emissions.

Objective 1. Describe the distribution of Ca-bearing minerals across soil parent materials in New York State.

Hypothesis: Apatite is more common in soils formed in granitic parent materials than sedimentary ones. Calcite will be present in only small amounts except where limestone is involved.

Hypothesis: Apatite and calcite have been weathered from surface soils to a greater degree than the silicate pools.

Objective 2. Assess the relative ability of different forest types to access Ca from different sources, including trace minerals.

Hypothesis: Within a soil type, forests dominated by ectomycorrhizal tree species, such as conifers, will have a greater fraction of plant Ca derived from non-silicate sources.

Hypothesis: Within a forest stand, differences between tree species in the proportion of Ca derived from apatite are relatively small, because of Ca recycling within the ecosystem.

We have chosen sampling designs that will make the results of these studies useful to future efforts to map the susceptibility of New York's forests to Ca depletion from acid rain. Determining critical loads and mapping the predicted condition of the forest resource is beyond the scope of the current project, but should be feasible after our first two Objectives are achieved.

F. Statement of Work and Schedule

Task Objectives, Methods and Deliverables

Objective 1. Describe the distribution of Ca-bearing minerals across soil parent materials in New York State.

Geographic Distribution of the Apatite Source

Our initial investigations were in New Hampshire soils formed in granitic glacial till. In work funded by the Agenda 2020 collaboration between the USFS and forest industry, we tested for the regional importance of apatite in the northeastern US (Figure 2). We collected soil samples from eight sites in upstate New York and Maine, in areas of granitoid parent material, and two sites in the Allegheny Plateau of Pennsylvania, which have soils derived from sedimentary rock (sandstone). The two sites in Pennsylvania were selected to bracket the southern extent of the Wisconsin glaciation (Figure 2). Sugar maple decline has been observed to occur on unglaciated soils of the Allegheny Plateau (Horsely et al., 2000), presumably because Ca depletion is more severe on older soils, while glaciers tend to rejuvenate reservoirs of fresh minerals in the soils that are available for weathering.

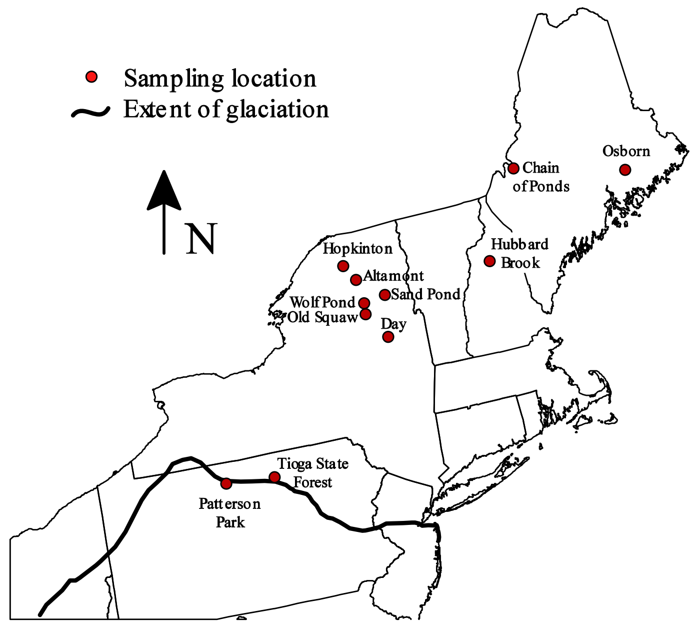

Figure 2. Location of the ten sites in the regional survey and the intensively studied site at the Hubbard Brook Experimental Forest.

We found that both of the sandstone sites had very little apatite, with the glaciated site having the least (Figure 3), suggesting that parent material is more important than glaciation in determining apatite availability in soils. As in New Hampshire, the Ca:P ratio of the 1 M HNO_3 extract in Maine and New York soils indicated that it was nearly entirely composed of apatite. In some soils, we expect calcite to be an important component of this pool, and our study is designed to measure both.

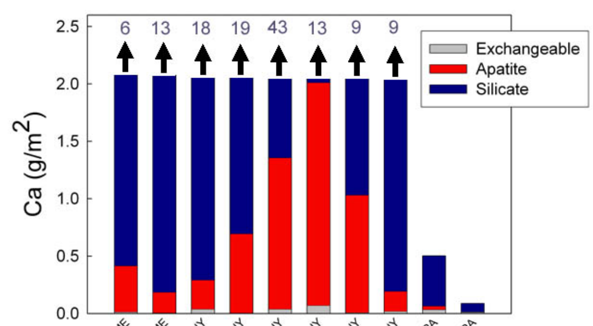

Figure 3. Concentrations of Ca in three operationally defined pools in ten C-horizon soil samples collected in New York, Maine, and Pennsylvania.

Igneous and metamorphic rocks, which are crystalline and unstable at Earth surface temperature and pressure, are generally more resistant to weathering than sedimentary rocks, which are cemented. Granitic parent materials, therefore, might be assumed to be poor at supplying Ca by mineral weathering. On the other hand, sedimentary rocks are formed from materials that have already been weathered. Since apatite is more readily weathered than the more common silicate minerals with which it is found, it is likely to be depleted from sediments. Relating the availability of Ca to the geological origin of the soil parent material will make it possible to better predict patterns of forest susceptibility to Ca limitation induced by acid rain.

Site selection (Yanai, Graduate Student)

We will select sites for sampling based on bedrock geology and the distribution of soil types. Soil series are defined by many factors, including the parent material. Since not all of the county soil surveys that describe New York State are available digitally, we will use both print and electronic sources to identify the most important soil series for analysis. Twenty sites will be selected, focusing on the most common forested soils within the major categories of bedrock that contribute to the parent material. Basing our sampling scheme on soil mapping units will provide a basis for extrapolation in future efforts to map the distribution of Ca sources in parent materials.

Sample collection and processing (Graduate Student, Research Support Specialist)

Soil will be sampled to the C horizon using five strata: O horizon, 0-10 cm, 10-20 cm, 20+ cm, and the C horizon. Soils collected from soil pits will be returned to the lab, dried at 105 °C, sieved through a 2-mm screen, and sent to the University of Michigan for analysis, as described below.