IMPACTS OF NITROGEN AND SULFUR DEPOSITION ON THE GROWTH OF RED SPRUCE AND SUGAR MAPLE IN THE UNITED STATES

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EXTENDED ABSTRACT

Total nitrogen (N) and sulfur (S) deposition in forest systems can have either positive or negative impacts on tree growth. The growth of many forests in North America is limited by N availability (Chapin et al. 1993, Killam 1994). Therefore, N fertilization is often a key component of forest management (Allen 2001), and in areas of N deposition, tree growth may be stimulated. However, N additions can sometimes be greater than what trees require and can negatively impact tree health and growth (Aber et al. 1995, Driscoll et al. 2001, McNulty et al. 2005). Systems where atmospheric deposition of N and S is greater than the critical load may be examples of such forest conditions. When critical loads are exceeded, tree health and growth may be compromised both directly and indirectly due to soil nutrient imbalances caused by leaching of base cations from the soil. Trees may have an increased susceptibility to drought and pest damage, aluminum (Al) toxicity in roots, reduced tolerance to cold, and a greater susceptibility to frost injury (Cronan and Grigal 1995, Driscoll et al. 2001, Fenn et al. 2006, McNulty et al. 2005, Ouimet et al. 2008). In the context of acidifying deposition of N and S, whether deposition has a positive or negative impact on tree growth may depend largely upon whether the critical load is exceeded by the deposition level, and it may follow an inverted U-shaped relationship similar to that which was hypothesized by Aber et al. (1995) for temperate forest systems that receive chronic, long-term N additions (Fig. 1).

To examine the relationships between N and S deposition and tree growth, preliminary analyses comparing the growth of sugar maple (*Acer saccharum* var. *saccharum*) and red spruce (*Picea rubens*) and critical acid load exceedances (positive and negative) were conducted for the full geographical ranges of both species in the United States. Sugar maple and red spruce were selected as the test species because both have experienced decline in areas of high N and S deposition (Ouimet et al. 2008, Shortle et al. 1997, Watmough 2002). Annual tree growth estimates for sugar maple and red spruce were obtained from the Forest Inventory and Analysis (FIA) database, and critical acid loads were calculated using the simple mass balance model (United Nations Economic Commission for Europe 2004) and three different levels of protection to tree health (base cation/Al soil solution ratio = 0.6, 1.2, and 10.0). The critical loads were compared against 2002 N and S deposition to estimate critical load exceedances. A series of multivariate ordinary least squares regressions were then conducted to examine the

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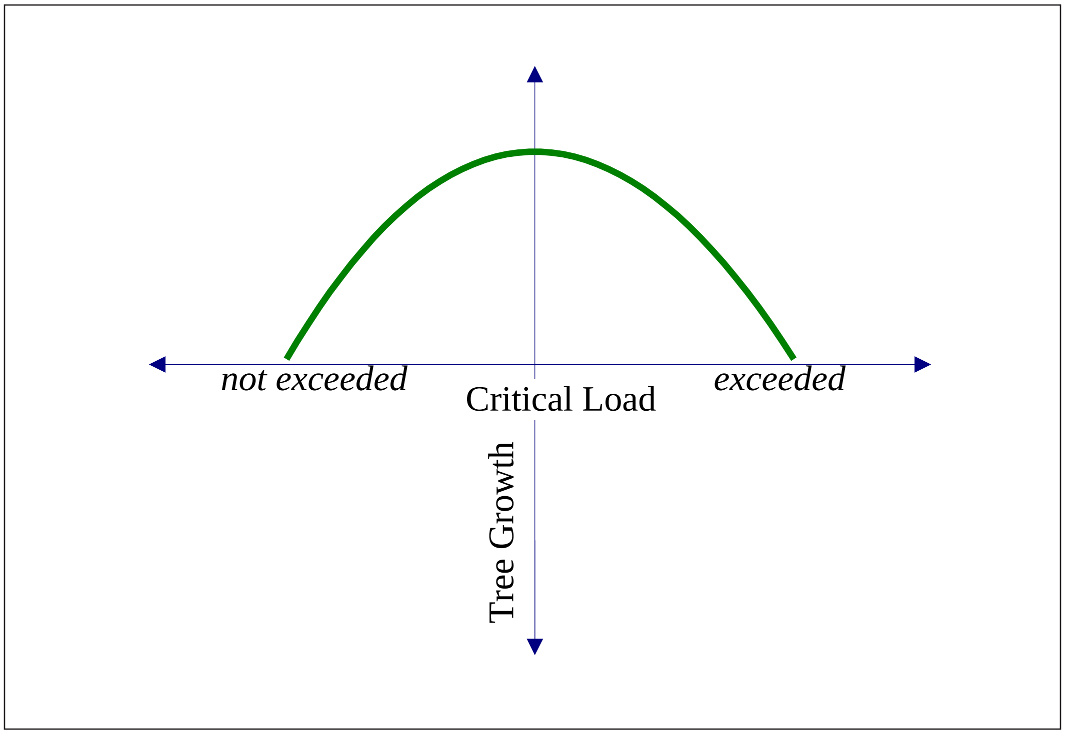

Figure 1.—Hypothetical relationship between tree growth and critical load exceedance (based on curve describing forest productivity as a function of long-term chronic N additions outlined in Aber et al. [1995]).

relationship between tree growth and N and S deposition. A quadratic functional form was used to test for evidence of the inverted U-shaped relationship between critical load exceedance and tree growth represented in Figure 1.

In addition, we conducted separate linear regression analyses relating N deposition and tree response in plots where critical load exceedance values were negative (i.e., plots where deposition levels did not exceed the critical loads), and analyses evaluating critical load exceedance and volume growth on plots where N and S deposition levels exceeded the critical loads. These separate analyses were conducted to test the hypotheses that tree growth is stimulated or "fertilized" by N when critical loads are not exceeded, and tree health and growth are impaired when the benefits of N deposition are replaced by the negative acidifying impacts of N and S deposition. The statistical results suggested that both species exhibited a quadratic functional form relationship between critical load exceedance and growth, although not significant at the $p = 0.05$ level. Based on critical loads determined using the base cations/Al ratio of 10.0, the linear regressions showed that growth of sugar maple was stimulated by N deposition on plots where critical loads were not exceeded ($p = 0.0013$), and red spruce growth was reduced on plots where 2002 N and S deposition levels exceeded the critical loads ($p = 0.0223$).

The objectives of this study will be to expand and improve on the preliminary analyses and further our understanding of the relationships between N and S deposition and red spruce and sugar maple growth. Parameters including initial tree volumes, plot elevation, stand basal area, and plot latitudes and longitudes will be included in the analyses to account for other sources of variation in the growth response. The ability to indirectly determine species-specific soil solution base cation/Al ratios will also be explored. It may be possible to calculate the base cation/Al ratio critical limit for red spruce and sugar maple based on the point of inflection in the quadratic relationship determined for each species. Previous comprehensive synthesis efforts have reported that the growth of red spruce and sugar maple seedlings was reduced by 20 percent, relative to controls at base cation/Al ratios of 1.2 and 0.6, respectively (Sverdrup and Warfvinge 1993). To date, however, the ability to test or confirm these species-specific critical limits for trees in the field has been limited. Furthermore, these exposure-response models of red spruce and sugar maple growth to N and S deposition may potentially be applied to evaluate the impacts of altered deposition levels on tree growth, and consequently, on provisioning ecosystem services through the use of the Forest and Agricultural Sector Optimization Model—Green House Gas version. If successful, these analyses and novel approach may prove to be a very effective way to evaluate the current condition of U.S. forests in response to N and S deposition, and how forest health could be improved with decreased deposition levels.

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