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Editorial

Chronic nitrogen additions at the Harvard Forest (USA): the first 15 years of a nitrogen saturation experiment

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Abstract

The delivery of reactive forms of nitrogen to the environment through the sum of agricultural and industrial activities now exceeds that from natural processes. Potential negative effects on forests were first proposed in 1985, and in the ensuing two decades, the process of N saturation has become a well-established and generally understood phenomenon, with a few remaining, significant unknowns.

One goal of this special section in Forest Ecology and Management is to report in detail on results from the first 15 years of chronic nitrogen additions to two contrasting forest types at the Harvard Forest in Petersham, MA, USA, with special reference to these two central questions. As similar projects elsewhere come to an end, the Harvard Forest experiment remains as one of the few on-going, long-term N saturation experiments. Longevity has enhanced the value of the chronic N experiment, and lead to a series of collaborative studies on plant, soil and microbial responses. Another goal of this special issue is to bring together and present the findings resulting from a diverse set of measurements enabled by the presence of this long-term experiment. A total of 11 papers are presented, in addition to this brief introduction.

Keywords: LTER; Nitrogen retention; Plant response; Overview

1. Introduction and background

Humans have altered the global and regional cycles of nitrogen more than any other element (Vitousek et al., 1997; Galloway et al., 2003). The delivery of reactive forms of nitrogen to the environment through the sum of agricultural and industrial activities now exceeds that from natural processes (Galloway et al., 2003). While N inputs to near-coastal and estuarine systems in the most densely populated and economically developed areas are dominated by the direct and indirect products of agricultural use (Driscoll et al., 2003), upland forests receive anthropogenic inputs of N mainly through wet and dry deposition (Aber et al., 2003).

Nihlgard (1985) first identified the potential for N inputs through air pollution to overcome widespread N limitations in temperate forests, saturating biotic demand and producing negative impacts on ecosystem processes. In less than two decades, the process of N saturation has become a well-established and generally understood phenomenon, at least in the temperate zone (Aber et al., 1998; Fenn et al., 1998; Gundersen et al., 1998, see also papers following Wright and Rasmussen, 1998) and has been discussed as a regional and anthropogenic ‘‘special case’’ in broader discussions of nutrient interactions and the development of biogeochemical cycles (Hedin et al., 1995; Vitousek et al., 1998).

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Despite this rapid increase in our understanding of N saturation in forests, two critical aspects of N saturation remain unclear.

The first is the rate at which N availability in forest ecosystems will increase with a given rate of N addition. One of the continuing surprises in N deposition research is the high retention efficiency for added N. Even stands in Central Europe which have experienced elevated N inputs for decades retain, on average, about 70% of current inputs (e.g. Dise et al., 1998; MacDonald et al., 2002). As most of the negative effects of N saturation are related to increased N cycling, nitrification and nitrate leaching (Aber et al., 1998), understanding the nature, kinetics and capacity of N retention mechanisms is critical for predicting the regional onset of saturation.

The second is the capacity for N saturation to reduce forest growth and increase tree mortality. While cases of forest decline and death have been linked either to N deposition or interactions of N with other pollutants (e.g. Schulze, 1989; McNulty et al., 1991, 1996; Magill et al., 2000, 2004) we understand relatively little about the mechanisms by which damage occurs or the physiological basis for this response (cf. DeHayes et al., 1999; Bauer et al., 2004).

2. Overview of this special section

The goal of this special section in Forest Ecology and Management is to report in detail on results from the first 15 years of chronic nitrogen additions to two contrasting forest types at the Harvard Forest in Petersham, MA, USA, with special reference to these two central questions.

In establishing hypotheses for this manipulation (Aber et al., 1989), we suggested that short- and long-term responses could be different not only in degree but in direction, with initial positive responses (increases in net primary production—NPP) yielding to negative responses (increased nitrate leaching, reduced NPP) over time. It was logical, then, that the chronic N addition experiment become a core activity of the Harvard Forest Long-Term Ecological Research (LTER) project. As similar projects elsewhere come to an end (e.g. the European NITREX experiments, Wright and van Breeman, 1995; Wright and Rasmussen, 1998), the Harvard Forest experiment remains as one of the few on-going, long-term N saturation experiments.

Longevity has enhanced the value of the chronic N experiment. As changes in ecosystem state have accumulated in response to long-term N additions, these plots have become increasingly intriguing to researchers from other institutions and disciplines. Another goal of this special issue is to bring together and present the findings resulting from a diverse set of measurements enabled by the presence of this long-term experiment. As this current set of results builds on earlier publications presenting intermediate responses and data from short-term experiments, we include here (see Appendix) a list of all previous papers resulting from research on the chronic N plots.

Our presentation includes a total of 11 papers in addition to this brief introduction. The first (Magill et al., 2004) describes the study sites and treatments in detail and presents the core set of long-term measurements, beginning in 1988. McDowell et al. (2004) follow with additional long-term data on soil water solutions collected below the forest floor. These two summarize the long-term responses of most relevance to our earliest set of hypotheses, and provide background and context for the more detailed experiments and observations presented in the papers that follow. (We have reviewed N saturation as a process in previous papers (Aber, 1992; Aber et al., 1989, 1998) as have others (Fenn et al., 1998; Gundersen et al., 1998)—and will not repeat those reviews here.)

Processes associated with N retention are addressed in several ways. First, Bowden et al. (2004) document significant reductions in soil CO_2 efflux with cumulative N additions (rather than increases that would be required by classical microbial immobilization). Micks et al. (2004a) present a set of intensive measurements of CO_2 flux over one growing season which also document no increase in soil respiration, even during periods of very rapid N immobilization. Nadelhoffer et al. (2004); Currie et al. (2004) and Micks et al. (2004b) present analytical and synthetic analyses of the retention and redistribution of ^{15}N added to the control and low N plots which suggest a need to rethink our view of N cycling in the soil system.

N saturation could also alter microbial communities and processes in ways that affect the fate of added N. Venterea et al. (2004) who have previously documented unexpectedly large gaseous losses of N as NO

(Venterea et al., 2003), examine here changes in gross and net rates of N transformations in the experimental plots. Compton et al. (2004) and Frey et al. (2004) employ different probes to assess the responses among soil microbial groups and indicators of biochemical processes.

Plant responses to added N at the Harvard Forest have been dramatic. Magill et al. (2004) demonstrate a tremendous decrease in NPP and increase in tree mortality in the high N pine plot. Bauer et al. (2004) present a detailed examination of changes in carbon assimilation and in the biochemical partitioning of nitrogen in the canopy of this stand which explain the decrease in NPP despite increased foliar N concentration.

3. Conclusion

The establishment and maintenance of the chronic N plots has provided a unique platform for research on long-term ecosystem response to chemical disturbance. Long-term results differ substantially from short-term, emphasizing the importance of LTER-like programs in delivering policy-relevant information. The research value of these plots increases with time, as evidenced by the growing number of collaborative and cooperative projects represented by the papers in this special section.

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Appendix A. Publications from the Harvard Forest Chronic N experiment, excluding the papers in this special section

Aber, J.D., Nadelhoffer, K.J., Steudler, P., Melillo, J.M., 1989. Nitrogen saturation in northern forest ecosystems—hypotheses and implications. BioScience 39, 378–386.

Aber, J.D., Melillo, J.M., Nadelhoffer, K.J., Pastor, J., Boone, R., 1991. Factors controlling nitrogen cycling and nitrogen saturation in northern temperate forest ecosystems. Ecol. Appl. 1, 303–315.

Aber, J.D., 1992. Nitrogen cycling and nitrogen saturation in temperate forest ecosystems. Trends Ecol. Evol. 7, 220–224.

Aber, J.D., Magill, A., Boone, R., Melillo, J.M., Steudler, P.A., Bowden, R., 1993. Plant and soil responses to 3 year of chronic nitrogen additions at the Harvard Forest, Petersham, MA. Ecol. Appl. 3, 156–166.

Aber, J.D., Magill, A., McNulty, S.G., Boone, R., Nadelhoffer, K.J., Downs, M., Hallett, R.A., 1995. Forest biogeochemistry and primary production altered by nitrogen saturation. Water Air Soil Pollut. 85, 1665–1670.

Aber, J.D., Ollinger, S.V., Federer, C.A., Driscoll, C., 1997. Modeling nitrogen saturation in forest ecosystems in response to land use and atmospheric deposition. Ecol. Modell. 101, 61–78.

Aber, J.D., McDowell, W.H., Nadelhoffer, K.J., Magill, A., Berntson, G., Kamakea, M., McNulty, S.G., Currie, W., Rustad, L., Fernandez, I., 1998. Nitrogen saturation in temperate forest ecosystems: hypotheses revisited. BioScience 48, 921–934.

Berntson, G.M., Aber, J.D., 2000. The importance of fast nitrate immobilization in N-saturated temperate forest soils. Soil Biol. Biochem. 32, 151–156.

Bowden, R.D., Steudler, P.A., Melillo, J.M., Aber, J.D., 1990. Annual nitrous oxide fluxes from temperate forest soils in the northeastern United States. J. Geophys. Res. 95, 13997–14005.

Bowden, R.D., Melillo, J.M., Steudler, P.A., Aber, J.D., 1991. Effects of nitrogen additions on annual nitrous oxide fluxes from temperate forest soils in the northeastern United States. J. Geophys. Res. 96, 9321–9328.

Castro, M.S., Steudler, P.A., Melillo, J.M., Aber, J.D., Bowden, R.D., 1995. Factors controling atmospheric methane consumption by temperate forest soils. Global Biogeochem. Cycles 9, 1–10.

Currie, W.S., Aber, J.D., McDowell, W.H., Boone, R.D., Magill, A.H., 1996. Fluxes of dissolved organic N and C in humid forest soils in relation to retention of long-term N amendments. Biogeochemistry 35, 471–505.

Currie, W.S., Aber, J.D., 1997. Modeling leaching as a decomposition process in humid, montane forests. Ecology 78, 1844–1860.

Currie, W.S., Nadelhoffer, K.J., Aber, J.D., 1999. Soil detrital processes controlling the movement of ^{15}N tracers to forest vegetation. Ecol. Appl. 9, 87–102.

Currie, W.S., Aber, J.D., Driscoll, C.T., 1999. Leaching of nutrient cations from the forests floor: effects of nitrogen saturation in two long-term manipulations. Can. J. For. Res. 29, 609–620.

Downs, M.R., Nadelhoffer, K.J., Melillo, J.M., Aber, J.D., 1996. Immobilization of a ^{15}N labelled nitrate addition by decomposing forest litter. Oecologia 105, 141–150.

Foster, D.F., Aber, J.D., Melillo, J.M., Bowden, R., Bazzaz, F., 1997. Forest response to disturbance and anthropogenic stress. BioScience 47, 437–445.

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Magill, A.H., Aber, J.D., 1998. Long-term effects of chronic nitrogen additions on foliar litter decay and humus formation in forest ecosystems. Plant and Soil 203, 301–311.

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