IFA International Workshop on Enhanced-Efficiency Fertilizers
Frankfurt, Germany, 28-30 June 2005

SETTING THE SCENE – THE INTERNATIONAL NITROGEN INITIATIVE

A. MOSIER and J. GALLOWAY
University of Florida, USA
University of Virginia, USA

University of Florida, Agricultural and Biological Engineering Department
Gainesville, Florida, USA
Email: armosier@ufl.edu

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"Setting the scene – the international nitrogen initiative"

A. Mosier [1] and J. Galloway [2]
[1]University of Florida, USA
[2]University of Virginia, USA

Introduction

This paper uses recently published information (e.g., Galloway et al., 2003; 2004a; INI 2005) to give an overview of the impact of human activities on the N cycle, and on the resultant ecological and human health consequences. The paper concludes with summary of the International Nitrogen Initiative (http://.initrogen.org), created as a follow up to the Second International Nitrogen Conference and is presented to the International Fertilizer Industry Association's International Workshop on Enhanced-Efficiency Fertilizers, 28-30 June, 2005.

Background

Nitrogen, contained in amino acids, proteins, and DNA, is necessary for life. While there is an abundance of nitrogen in nature, almost all is in an unreactive form (gaseous nitrogen, N_2) that is not usable by most organisms. N compounds fall into two groups – non-reactive and reactive. Non-reactive N is N_2. Reactive N (Nr) includes all biologically active, photochemically reactive, and radiatively active N compounds in the atmosphere and biosphere of the Earth. Thus Nr includes inorganic reduced forms of N (e.g., NH_3, NH_4^+), inorganic oxidized forms (e.g., NO_x, HNO_3, N_2O, NO_3^-), and organic compounds (e.g., urea, amines, proteins, nucleic acids). In the absence of human intervention, the supply of reactive nitrogen in the environment is not sufficient to sustain the current abundance of human life. Thus humans learned in the early 20th century how to convert gaseous N_2 into forms that could sustain food production. Over 40% of the world's population is here today because of that capability.

Problem

There are two major problems with nitrogen: some regions of the world do not have enough reactive nitrogen to sustain human life, resulting in hunger and malnutrition, while other regions have too much nitrogen (due mainly to the inefficient incorporation of nitrogen into food products and to the burning of fossil fuel) resulting in a large number of major human health and ecological effects. The rate of change of the problem is tremendous, probably greater than that for any other major ecological problem. For example, half of the synthetic nitrogen fertilizer ever used on Earth has been used in just the last 15 to 20 years. Opportunities to reduce these problems are plentiful. A prerequisite to reducing these problems is the development of a sound scientific base on which to begin to discuss policy options. To approach these options we pose **four central questions of nitrogen distribution and effects:**

1. Reactive N is introduced to the natural terrestrial environment primarily by biological nitrogen fixation in forests and grasslands, particularly in the tropics. Human activity introduces reactive N inadvertently by fossil fuel combustion and purposefully through biological nitrogen fixation associated with agricultural crops and the Haber-Bosch process which allows the manufacture of synthetic fertilizer.
How has human introduction of reactive nitrogen changed with time relative to natural sources?

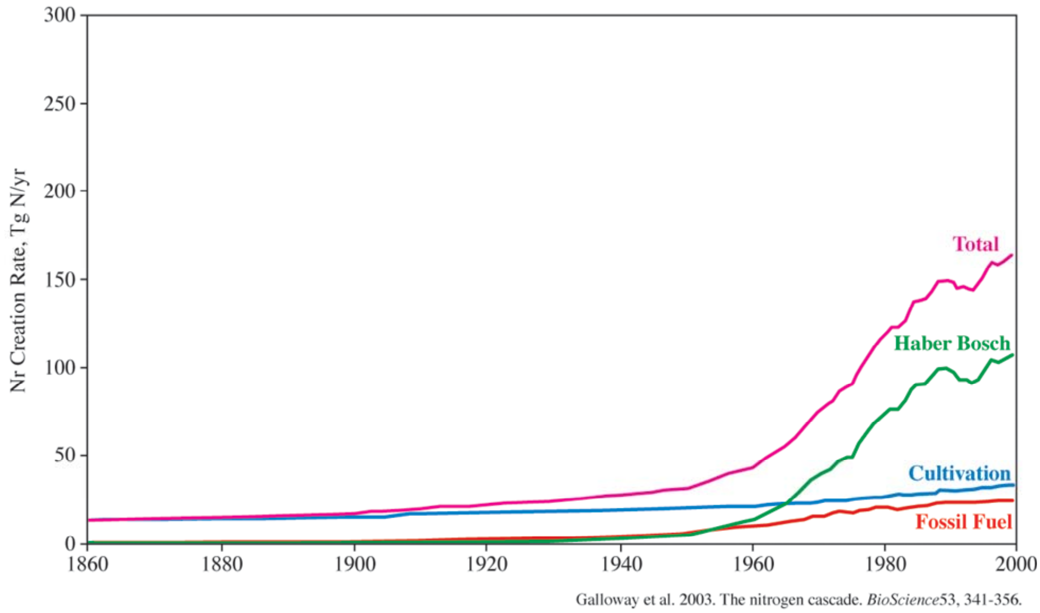

Figure 1: Anthropogenic creation rates of reactive nitrogen by the Haber-Bosch process, biological nitrogen fixation associated with agricultural crops, and combustion of fossil fuels. The units are Tg nitrogen per year (or millions of metric tons per year) over the entire planet.

In 1860, natural nitrogen fixation on the land masses of the planet introduced between 100 to 200 million metric tons per year of reactive nitrogen into the terrestrial environment. Within the last few decades, human activities have roughly matched this supply. The rate of human creation continues to grow, particularly from the manufacture of synthetic nitrogen fertilizer.

2. Once introduced into the environment, reactive nitrogen can be chemically transformed to different nitrogen species, many of them in gaseous forms (NH_3 and NO) and thus become available for emission to the atmosphere.Once emitted these gases can be transported to environments thousands of kilometers from the point of emission and deposited to ecosystems. **How much have rates of deposition from the atmosphere of reactive nitrogen changed relative to natural conditions?**

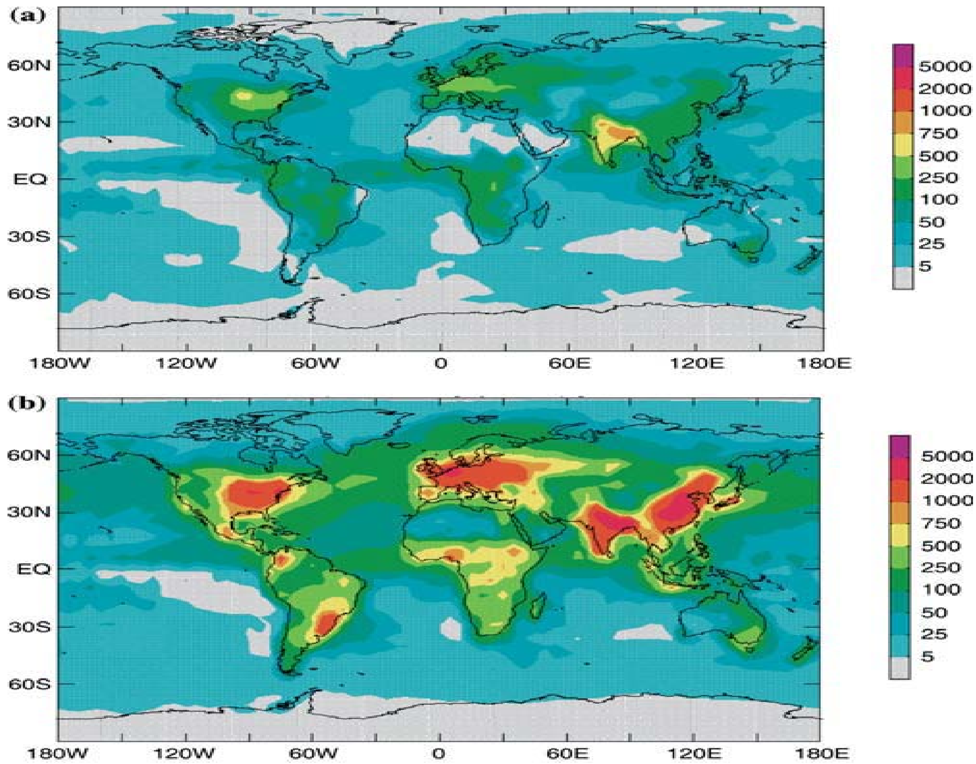

Figure 2: Spatial patterns of total inorganic nitrogen deposition in 1860 (top) and early 1990 (bottom) in units of, kg nitrogen per square kilometer per year (Galloway et al., 2004)

Note the large increases in many parts of the world, but note also that in some regions deposition of nitrogen pollution form the atmosphere remains low.

3. In addition to atmospheric emission and transport, much nitrogen is transported to coastal marine waters. **How much has human activity changed the flow of reactive nitrogen into coastal waters?**

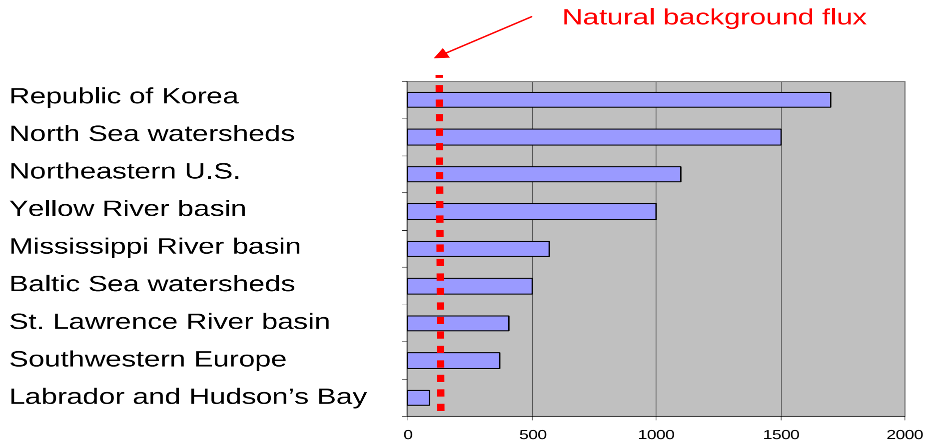

Figure 3: Flux of reactive nitrogen from the landscape to coastal oceans in rivers for key contrasting regions of the world in the temperate zone, in units of kg nitrogen per square kilometer of watershed area per year (Howarth et al. 1996, 2002; Bashkin et al. 2002).

Human activity has had an incredible influence on nitrogen fluxes to coastal oceans in some parts of the world, and very little effect elsewhere. The nitrogen cycle is most altered where farming and industrial activity is greatest.

4. The increased introduction of reactive nitrogen to the environment by human action, and the increased dispersion of this nitrogen via the atmosphere and rivers raises question #4: **What are the consequences on ecosystem and human health?**

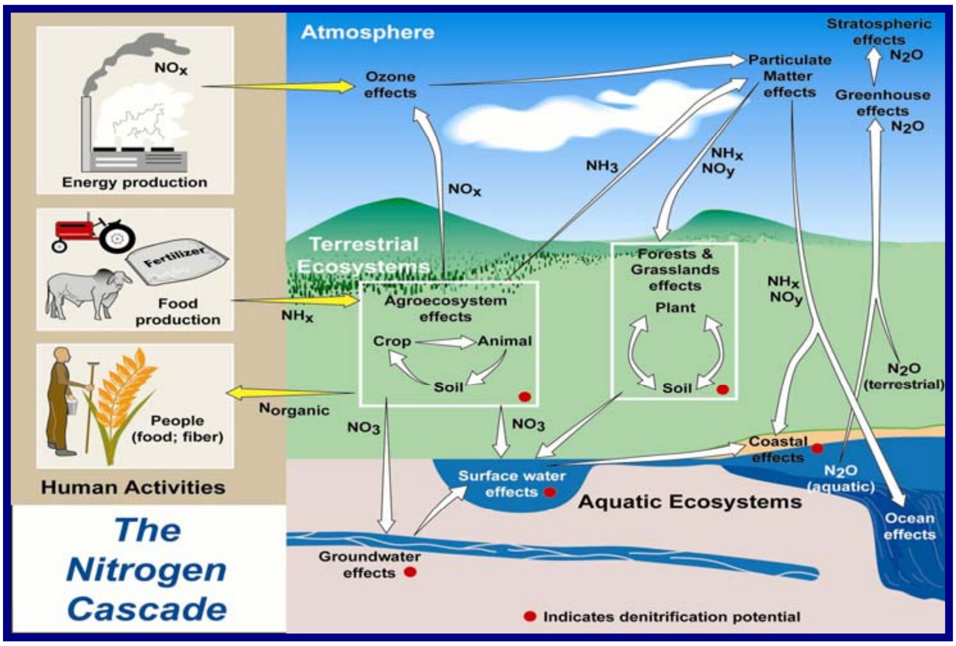

Figure 4: The movement of nitrogen through the environment and the associated environmental effects (Galloway et al., 2003).

Nitrogen is now known to be unusual among the elements that have had their cycles significantly perturbed by human action. As nitrogen moves along its biogeochemical pathway, the same atom can contribute to many different negative impacts in sequence: as NO_x it can increase ozone concentration in the atmosphere, decrease atmospheric visibility, and increase acidity of precipitation; following deposition it can increase soil acidity, decrease biodiversity, lead to coastal eutrophication, and then emitted back to the atmosphere as nitrous oxide it can increase greenhouse warming, and decrease stratospheric ozone. Nitrogen can be transported to any part of the Earth system, no matter where it was introduced. This sequence of effects has been termed the nitrogen cascade. The concept of the cascade, and the extensive research that underlies it, has allowed us not only to determine the linkages among the various aspects of the nitrogen cycle, but also to begin to assess how changes in one part of the cycle can delay or enhance the transfer of nitrogen to other parts of the cycle. The cascade continues as long as the nitrogen remains active in the environment, and it ceases only when reactive nitrogen is stored for a very long time, or is converted back to non-reactive N_2. The enormous significance of nitrogen is that it is linked to so many of the major global and regional environmental challenges that policymakers face today: ozone layer depletion, acidification of soils and surface waters, global warming, surface and groundwater pollution, biodiversity loss, and human health and vulnerability.

Challenge

The challenge of nitrogen is how to optimize the use of nitrogen to sustain human life while minimizing the negative impacts on the environment and human health. It is critical to the health of humans and ecosystems that this challenge be met. It is doubly critical because without action, future populations will be more stressed either due to nitrogen limitations or due to nitrogen excesses. As human population continues to increase, dietary preferences change and as income and accessibility of animal protein sources to a wider array of people increases the potential increase in Nr in the coming 50 years is large (Fig. 5). The trajectory that the Nr curves actually fall and the resultant environmental impacts remain to be seen.

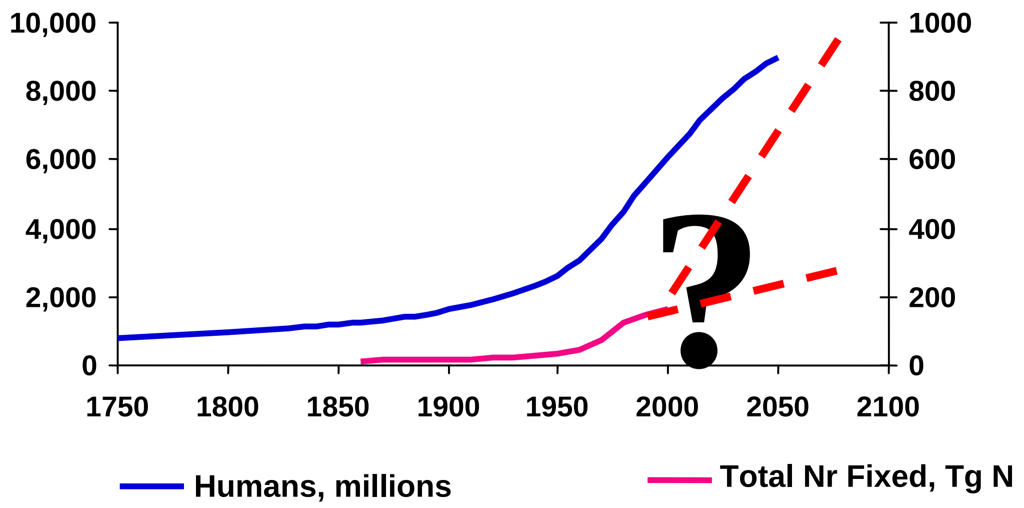

Figure 5: Possible trajectories of future Nr creation. Total Nr Fixed, right axis; Global Population, left axis (based on Galloway, 2003).

Opportunities

Numerous opportunities for intervention exist that can increase the availability of nitrogen in deficient regions, and limit the exposure of humans and ecosystems to the problems of excess nitrogen. The opportunities include scientific, engineering, social and political instruments, and when used in an integrated manner, will enable society to meet the challenge.

The Process—the International Nitrogen Initiative (the INI)

The participants of the Second International Nitrogen Congress unanimously recommended that an international organization be developed to provide a mechanism for integration of research and policy issues relating to nitrogen. Following on that recommendation, the International Nitrogen Initiative was formed in early 2003 under the sponsorship of Scientific Committee on Problems of the Environment (SCOPE) and the International Geosphere-Biosphere Program (IGBP).

SCOPE, established by the International Council for Science (ICSU) in 1969, is an interdisciplinary body of natural and social science expertise focused on global environmental issues, operating at the interface between scientific and decision-making instances. IGBP, established by ICSU in 1986, is an international scientific research program that brings together researchers from biology, physics, chemistry, geology and other disciplines to undertake a study of global change in the context of the Earth System.

The overall goal of the INI is to *optimize nitrogen's beneficial role in sustainable food production and minimize nitrogen's negative effects on human health and the environment resulting from food and energy production*.

The INI is organized on a regional basis with an overall umbrella body (Steering Committee) to provide coordination, a Science Advisory Committee and a number of Consultants.Regional INI centers have been established in North America, Latin America, Asia, Europe and Africa.The activities for a given Center are dependent on the 'maturity' of nitrogen science and policy for that region. Each Regional Center uses a three-phased approach to work towards the overall goal of the INI, with coordination provided by the Steering Committee:

Phase I: Assessment of knowledge on N flows and problems
Phase II: Development of region-specific solutions.
Phase III: Implementation of scientific, engineering and policy tools to solve problems.

Phase I is organized around crosscutting themes, including topics of biological nitrogen fixation, denitrification, agriculture, fertilizers, animal production, human waste, energy production/use and policy approaches. The regional assessments will be integrated to create an overall global assessment. In Phase II, region-specific solutions towards problems identified in Phase I will be proposed. Phase III activities will be primarily directed towards working with critical groups to implement identified solutions. It is important to note that the phases do not have to occur in sequence.

The INI was active in 2004. Two INI-wide workshops were conducted. In January 2004, the workshop on Agriculture and the Nitrogen Cycle was held in Kampala, Uganda. Results of the workshop are available on the INI website, and also in the book published by Island Press (Mosier et al., 2004). At the other end of the nitrogen biogeochemical cycle, the workshop on Advanced Approaches to Quantify Denitrification was held in Woods Hole, MA USA. Papers from the workshop have been submitted to Ecological Applications; a summary report by Davidson and Seitzinger (2004) is available on the INI website. In 2005 the INI is planning a workshop on policy aspects of nitrogen, and several other workshop topics are under discussion.

In addition to the workshops, the INI prepared a preliminary assessment, "Changes in the Global Nitrogen Cycle as a Result of Anthropogenic Influences" (Galloway et al. 2004b) for the Third International Nitrogen Conference. Prepared by the INI Steering Committee, the document reviews what is known and unknown about the impact of humans on the nitrogen cycle, and the resulting impacts on ecosystems and people. The assessment is currently being revised based on comments received at the Conference.

Policy tools are needed to implement scientific, engineering social agendas to solve the identified problems. Policy makers at the governmental level must be involved in the steps needed, if the problems of nitrogen supply are to be reversed. Towards that end, the Third International Nitrogen Conference and the INI jointly developed the Nanjing Declaration, which lays out the major issues concerning nitrogen and sets the stage for the continued development of an integrated, global approach to meet the challenge of nitrogen. The following document was created to encourage the involvement of international policy makers:

Nanjing Declaration on Nitrogen Management

Presented to the United Nations Environment Programme. Nanjing, People's Republic of China, 16 October 2004.

The participants of the Third International Nitrogen Conference, held in Nanjing, People's Republic of China, 12 – 16 October 200

AFFIRM the principles of the Millennium Development Goals and the World Summit on Sustainable Development to speedily increase access to basic human needs such as energy, water, food security and the protection of human health and biodiversity.

AFFIRM the scientific findings of the International Nitrogen Conferences and the International Nitrogen Initiative (INI).

ACKNOWLEDGE that reactive nitrogen plays a vital role as a nutrient in the production of food, fiber, and other societal requirements for the growing population.

RECOGNIZE that, although anthropogenic production of reactive nitrogen exceeds natural creation in many regions of the world, other areas suffer from the opposite problem **-** a deficiency of reactive nitrogen in the soil, contributing to food insecurity and malnutrition. These areas include most of Africa and parts of South America and Asia.

RECOGNIZE that, although many people suffer from malnutrition, a growing proportion of the world's population consumes excess protein and calories, which may lead to human health problems. The associated production of these dietary proteins (especially animal products) leads to further disturbance of the nitrogen cycle.

ACKNOWLEDGE that reactive nitrogen is a by-product of fossil fuel combustion that contributes to the welfare of humanity by supplying electricity, transportation and energy.

NOTE WITH SERIOUS CONCERN that in many parts of the world, significant amounts of reactive nitrogen are lost to the environment in agricultural and industrial production and fossil fuel combustion.This has lead to disturbances in the nitrogen cycle, and has increased the probability of nitrogen-induced problems such as pollution of freshwaters, terrestrial and coastal ecosystems, decreasing biodiversity and changing climate and pose a threat to human health.

ARE FURTHERMORE CONCERNED that, with the rapidly increasing world population, the disturbance of the nitrogen cycle will become worse unless adequate measures are taken.

AFFIRM that since the different forms of reactive nitrogen can be transformed into one another and are very mobile in the environment, an integrated approach to optimize nitrogen use whilst preventing nitrogen pollution, is necessary.

ARE KEENLY AWARE of the urgent need for international cooperation to decrease the disturbance of the nitrogen cycle.

ENCOURAGE countries to coordinate their research, exchange solutions, and work together with the International Nitrogen Initiative and its Regional Centers, including participating in the International Nitrogen Conferences as recurrent opportunities to discuss scientific progress and issues related to policy.

CALL UPON the United Nations Environment Programme, as the environmental conscience of the United Nations system, to promote understanding of the nitrogen cycle, assess consequences of its disturbance, provide policy advice and early warning information, and catalyze and promote international cooperation. This should be done in conjunction and close cooperation with: the Consultative Group on International Agricultural Research, the Food and Agriculture Organization, the World Health Organization and other appropriate United Nations organizations, stakeholders, the International Nitrogen Initiative and its Regional Centers, and other relevant organizations.

WELCOME the new International Assessment on Agricultural Science and Technology for Development and recommend that it should fully consider agricultural nitrogen issues.

Hereby declare their commitment to facilitate the optimization of nitrogen management in food and energy production, and environmental protection.

Call upon their national governments to optimize nitrogen management on a local, regional and global scale by:

1. **Supporting further assessment of the nitrogen cycle, its benefits for humankind, and its consequences on human health and the environment.**

2. **Focusing efforts on increasing the efficiency and effectiveness of agricultural production and energy use, while decreasing the adverse effects of reactive nitrogen.**

3. **Promoting exchange of information and technology, raising public awareness, encouraging research and development of solutions to reactive nitrogen problems, and monitoring disturbances of the nitrogen cycle.**

4. **Taking action to enhance availability to reactive nitrogen as food, fiber and other basic needs in regions of nitrogen deficiency and avoid nitrogen pollution. This can be done by continual development and promotion of:**

a) A code of good agricultural, forestry, and aquacultural practices, recognizing the needs for specific practices to be tailored to specific conditions and improving utilization of nitrogen in food production;

b) Strategies for sustainable energy use to prevent the formation of nitrogen oxides in fossil fuel combustion, and

c) Application of emission reduction technologies (e.g. wastewater treatment, selective catalytic reduction).

Prof. Zhoaliang Zhu Soil Science Institute Chinese Academy of Sciences People's Republic of China	Prof. Katsu Minami National Institute of Agro-environmental Sciences Japan	Prof. James Galloway University of Virginia USA
Co-Chair of the Conference	Co-Chair of the Conference	Chair of INI

Interactions with Other Activities

The INI is actively interacting with many organizations and is introducing a number of new projects. We encourage you to check on INI activities on the World Wide Web at http//: initrogen.org

Conclusion

Just as human activities have had a profound impact on the nitrogen cycle at global and regional scales, so can human activities reduce the consequences of nitrogen on the environment and on human health. Enhancing the efficiency of N-fertilizers is a needed step for both agronomic and environmental concerns. The broad participation by scientists and other interested parties, are key components of the broader picture of how we can continue to reap the benefits that nitrogen has to offer society, while minimizing the detrimental consequences. The INI was created to communicate to the broader world the issues concerning nitrogen. In that regard, the Nanjing Declaration approved at the Third International Nitrogen Conference is a critical step in the direction of engaging policy makers in the nitrogen debate. Thus we urge us all to not only move forward on our scientific assessment, but to also include wide variety of stakeholders in the discussions of our findings and what they mean for society at large.

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