Optimizing Nitrogen Management in Food and Energy Production & Environmental Protection

# 2nd international nitrogen conference

# CONTRIBUTED PAPERS

Edited by:
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# Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection

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# OPTIMIZING NITROGEN MANAGEMENT IN FOOD AND ENERGY PRODUCTION & ENVIRONMENTAL PROTECTION

# Preface

The First International Nitrogen Conference was held in The Netherlands in 1998. Its primary focus was on the effects of increased cycling of nitrogen on regional, continental, and global scales. The main contributions were from European scientists.

Three significant messages emerged from the First Conference: (1) increased circulation of nitrogen in the atmosphere and biosphere is occurring in all parts of the globe; (2) nitrogen has a range of well-understood beneficial and detrimental consequences for people and the environment; and (3) scientists and decision makers need to work together to develop integrated approaches to solve nitrogen-related problems.

These insights led to the recommendation that a Second International Nitrogen Conference be held in the U.S. during the autumn of 2001. The Second Conference concentrated primarily on North America and Europe with a secondary focus on Asia – the most rapidly developing part of the world.

More than 400 scientists, engineers, resource managers, decision makers, and policy analysts attended the Conference. The participants came from 30 nations and six continents of the world. The disciplines represented included agronomy, animal nutrition, aquatic ecology, atmospheric chemistry and physics, atmospheric modeling and meteorology, biochemistry, biogeochemistry, crop science, environmental science, forestry, geography, geology, horticultural science, human nutrition, journalism, law, limnology, medical and environmental health sciences, oceanography, plant ecology, plant pathology, plant physiology, political science, poultry science, and soil science.

The participants represented many stakeholder groups concerned with reactive nitrogen production, uses, and consequences once it begins to cycle in the environment. They included leaders in international, federal, state, and provincial government agencies; environmental and public interest groups; business leaders in crop and animal agriculture, energy production, transportation, and communications; and professional societies and trade associations.

Cutting-edge nitrogen science and policy issues were explored through several approaches before, during, and after the Conference:

- A 2.5-day Workshop among authors of plenary papers 4 months before the Conference.
- 18 plenary paper presentations during the Conference.
- 19 oral and poster sessions featuring 285 presentations.
- 3 lively and well-attended Roundtable Discussions.
- 50 sessions of NitroGenius played during the Conference – an interactive computer simulation game in which participants assume the roles of different stakeholders in making decisions to optimize nitrogen management.
- More than 500 answers from conference participants to a series of nitrogen science and policy questions.
- Statements developed by groups of conference participants to identify "common ground" on issues that stimulated debate during the Conference.
- Suggestions by individual conference participants that will contribute to the ability of their home country, institution, or agency to optimize nitrogen management in their society.
- Publication of peer-reviewed contributed papers in *TheScientificWorldJOURNAL* and preparation of plenary papers for a forthcoming issue of *Ambio*.

The scientific findings and recommendations in the papers contained in this volume are based on the products of all of these approaches.

# Foreword *by Marjanne Sint*

*Secretary General, Dutch Ministry of Housing, Spatial Planning and the Environment*

This conference is entirely devoted to nitrogen. But why should we worry about nitrogen? On a global scale the nitrogen cycle is tilting out of balance. This is due primarily to two factors: an increase in the world's population and rising living standards. Both result in an increased demand for food and energy which in turn leads to an accumulation of nitrogen compounds in the environment. This causes three major problems. First, in urban areas human health, lung function in particular, is affected by a mixture of ozone, nitrogen dioxide and particulate matter. All of these compounds, entirely or in part, originate from reactive nitrogen. Nitrate in groundwater also poses a health threat when used for the preparation of drinking water since a high concentration of nitrate can be harmful, especially to babies. A second problem is that the deposition rate of reactive nitrogen causes eutrophication of ecosystems, degradation of biodiversity and poor surface water quality. Ecosystems in areas with a high density of livestock rearing, such as North Carolina (U.S.) and Western Europe, are particularly affected by the surplus of nutrients. And, thirdly, the world's climate is threatened by the emission of greenhouse gases, with nitrous oxide being one of the most important.

But what can we do about it? At the first nitrogen conference, which was held in The Netherlands in 1998, researchers and policy makers from around the world discussed the environmental pollution caused by nitrogen compounds. It was acknowledged that environmental problems due to the surplus of nitrogen compounds affect the entire world, and are likely to increase in the coming decades. An important conclusion was that nitrogen can lead to a cascade of effects, and that therefore measures to mitigate effects should be focused on the reduction of reactive nitrogen compound production. This second conference has built on these premises. It was specifically aimed to fill gaps in scientific knowledge of nitrogen management and its beneficial and detrimental effects on society and the environment. It has recommended improved policies for management of nitrogen in food production, energy production and use, and environmental protection. It has aimed to increase public understanding of the nitrogen cycle of the Earth and its linkages with the social and economic dimensions for food, energy and environmental management systems.

As in many other countries, energy consumption is high in The Netherlands due to the presence of industry, automobiles and significant meat production. All these factors lead to high nitrogen oxide and ammonia emissions, with all the attendant problems for human health and the natural environment. These problems are particularly pressing in The Netherlands, which is one of the most densely populated countries in the world: 230 times smaller than the United States, but with 16 million inhabitants. In such a small, densely populated and highly industrialized region, one can see all too clearly the impact high nitrogen emissions have on human health and the natural environment. An active policy to reduce emissions of nitrogen oxide and ammonia is therefore vital for us.

The Dutch government has been successful in pursuing just such a policy since the early 1980s. Nitrogen oxide

# Foreword *by Linda J. Fisher*

*Deputy Administrator, United States Environmental Protection Agency*

The adverse human health and ecological effects of nitrogen compounds have been a concern for many years now. Concern over nitrogen's role in the acidification of lakes and streams goes back over a quarter century in the United States. Since 1971, emissions of $NO_x$ into the air have been controlled by the federal Clean Air Act because of its effect on human health. And over the past decade, with the rapid expansion of large animal feedlots, in terms of both size and numbers, we have seen increasing evidence of the ways in which animal wastes can seriously degrade the quality of freshwater and estuarine ecosystems.

At the same time, it is hard to identify a substance that serves so many useful purposes in our modern societies and economies. Because nitrogen is a byproduct of the combustion of all fossil fuels, it is woven into the fabric of our economic life. More fundamentally, it is an essential fertilizer for the world's food supply. So, in a sense, nitrogen can be seen as a symbol of a much larger environmental question, a question that is key to our hopes for a better world in the future. How do we provide the necessities and amenities that enable humans to prosper in happiness and good health, while simultaneously controlling the byproducts and secondary effects of the very materials necessary to achieve that prosperity?

In the past, the U.S. Environmental Protection Agency (EPA), the primary environmental regulatory agency in the United States, tended to take a fragmented approach to answering that question. Because cars were a major source of airborne $NO_x$, we required new cars to incorporate catalytic converters. We required controls on fossil-fuel fired power plants to limit emissions of pollutants, including $NO_x$, that acidify lakes and streams in sensitive regions of the country. In a sign of our changing understanding of the forms and sources of nitrogen pollution, we are in the process of developing regulations to control how and where animal feedlots discharge their wastes. In total, three different EPA offices have major efforts underway to better understand and control the adverse environmental effects of nitrogen: our Offices of Water, Air, and Research and Development.

Until recently, however, something important was missing from our understanding of nitrogen and our efforts to control its adverse effects. Simply put, we were missing the "big picture" that unfolds when one recognizes the integrating nature of nitrogen as a pollutant. For example, it was fine to limit emissions of nitrogen one source at a time, one environmental medium at a time, until we realized that all the sources and all the media were inextricably interrelated. When we learned that up to 40 percent of the nitrogen affecting water quality in the Chesapeake Bay came from the air, not just from farm runoff or wastewater treatment plants, we realized that protecting the Bay was not simply a water quality problem. If we wanted to address water quality issues, we had to worry about air quality as well because air quality was linked hand-in-glove to water quality.

Nor was nitrogen pollution a localized problem that could be solved by localized actions. For example, eutrophication in our coastal waterways has been traced to releases of nitrogen and other nutrients originating far upstream in the

## Foreword *by Marijanne Sint* (continued)

emissions are now 20 percent lower than in 1980, and ammonia emissions have been reduced by 30 percent. However, we still have a long way to go to reach emission levels that have no damaging effect on humankind and nature. The Netherlands hopes to reduce emissions of both substances by a further 30 percent over the next ten years, and in the long-term by 90 percent from 1980 levels. To achieve these ambitious goals, Dutch society needs to switch to sustainable methods of agriculture and energy supply. We are therefore approaching the problem from several angles: an integrated European approach, national $NO_x$ emissions trading and a fully integrated national approach to reactive nitrogen.

Europe is working towards a coherent, integrated approach to what is, after all, a cross-border problem. Both the UN and the EU have taken initial steps towards tackling the nitrogen problem more comprehensively. A multi-pollutant/multi-effect approach has been adopted, a comprehensive strategy designed to reduce four effects by reducing emissions of four substances in a cost-effective way. It will simultaneously address the problems of acidification and eutrophication, and the effect of ozone on human health and vegetation. National emissions ceilings have been set at both UN and European levels, and laid down in the Gothenburg Protocol and the National Emission Ceiling Directive.

Another tool that has been developed to achieve these ambitious goals is a nitrogen oxide emissions trading system. We have committed ourselves to developing a system free of the inherent limitations of the existing cap-and-trade systems that have been employed by other countries. The trading instrument permits free entry into the economy while still addressing the need to reduce $NO_x$ emissions within the region. Since 1997 the government of the Netherlands has been collaborating with industry working groups to develop a mechanism that can provide reductions in $NO_x$, in line with short and long-term government objectives, while maintaining flexibility and cost-effectiveness for facility emission controls.

Our third angle of approach is to gain more knowledge of the interaction between individual nitrogen problems. We can stop problems from being passed on to other parts of the environment or other policy areas, or merely left for the future, by taking the reduction of reactive nitrogen as our basic aim. The multi-pollutant/multi-effect approach agreed upon in Europe is a first step on the way to a fully integrated approach to the surplus of reactive nitrogen. To improve our knowledge of this interaction, we are developing a Nitrogen Decision Support System, or NDSS, which takes into account all the effects of any given measure on reactive nitrogen compounds. The NDSS forms the basis for NitroGenius, a nitrogen management game that allows the player to make decisions for the politician, the farmer, the industrialist and the consumer. In each of these roles, the focus must not just be on the player's own agenda, but on solving the Dutch nitrogen problem. This effectively illustrates the integrated nature of the problem. Here at this conference, you have been the first to have the opportunity to test NitroGenius on a special computer network set up for this purpose.

This conference has provided the perfect forum to exchange ideas with fellow scientists, and has provided the opportunity to urge policy makers who attended to make the right decisions in the future!

## Foreword *by Linda J. Fisher* (continued)

watershed. Becauce atmospheric $NO_x$ emissions also could travel long distances, we needed to look at region-wide solutions that incorporated actions to control sources outside the region.

The EPA now looks at nitrogen as one of the best examples of the kind of environmental issue that will consume much of our attention in the 21st century. In other words, a single set of compounds that is a root cause of a highly complex, interrelated set of problems. Nitrogen is emitted by multiple sources, and it moves through multiple environmental media to affect multiple human health and ecological endpoints. Consequently, any set of environmental policies that hopes to effectively solve this kind of complex problem must see the big picture. We must take into consideration the whole nitrogen cycle, and integrate policies across environmental media, recognizing that specific strategies have to be designed for specific sectors of industry and society.

And that, in a nutshell, is why the EPA welcomed the opportunity to support the Second International Nitrogen Conference, participate in these important discussions, and encourage the work of the international research community. Each participant in this event is an expert in some specialized aspect of the science of nitrogen. Yet, the work of each individual is undoubtedly linked in myriad, and sometimes unforeseen, ways with the work of dozens of other participants. It is imperative that those links be identified, strengthened, and expanded as we move forward. It is essential that the work of each enriches the other, so the sum of all the science being conducted on nitrogen is greater than the individual pieces taken separately.

In this sense, the participants at this conference are very much like the dedicated people who work on nitrogen-related issues at the EPA. Each individual is an expert in one specialized area of nitrogen control, whether it is related to air quality, water quality, or research. Through our big picture understanding, however, each of them is becoming increasingly aware of the work being done in other parts of the Agency. To be successful, EPA's overall nitrogen strategy has to incorporate and integrate those many individual pieces into a comprehensive, effective whole. Our nitrogen control strategy, like nitrogen-related scientific studies, has to be greater than the sum of its parts.

In years past, the research community has provided the bedrock knowledge that has helped EPA and environmental agencies around the world design policies to protect human health and the environment. Without the good work of the international scientific community, our hands are tied by ropes of ignorance and uncertainty. But the more that the scientific community learns, the more those ropes are loosened. And, as each learns more about the other's work, and ideas are cross-fertilized, this growing body of knowledge helps government agencies like the U.S. EPA design more far-reaching, encompassing, and effective policies for protecting human health and the environment from the deleterious effects of nitrogen, while allowing society to reap the benefits of the positive aspects of this essential substance. We look forward to hearing about the results of this conference, especially as they contribute to even better nitrogen research — and policy — in the future.

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- American Dairy Science Association
- American Society of Animal Science
- Poultry Science Association
- American Meat Science Society

The Conference was planned over a 2-year period. During that time, the 9 members of the Organizing Committee (Mary Barber, Rona Birnbaum, Jan Willem Erisman, Jonathan Garber, Richard Haeuber, Kaj Sanders, Sybil Seitzinger, Stan Smeulders, and Joe Wisniewski) and the 22 members of the Science and Policy Program Committee (Mary Barber, Ton Bresser, William Chameides, Robin Dennis, Jan Willem Erisman, Robert Howarth, Charles Lander, Jerry Melillo, William Moomaw, Arvin Mosier, Rosamond Naylor, Kaj Sanders, Kenichi Satake, David Schimel, Sybil Seitzinger, Stan Smeulders, Robert Socolow, Jeffrey Stoner, Peter Vitousek, Ford West, Robert Wright, and Zhaoliang Zhu) worked diligently with the Conference Co-Chairs (Jim Galloway and Ellis Cowling) to ensure that the conference was successful.

We also appreciate the efforts of the publishers involved with the products from the Conference, namely Anne Vindenes Allen and Tara Retzlaff of TheScientificWorld; Janjaap Blom of A.A. Balkema Publishers; and Wisniewski and Associates, Inc. who oversaw the review process of all the submitted papers.

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# Contents



## N Cycling in Agroecosystems

## Biosphere-Atmosphere Nitrogen Exchange

## N Cycling in Forested and Aquatic Ecosystems

## Nitrogen Management and Policy

### Agricultural Systems

**Economic and Regulatory Systems**

Research Article
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# Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Summary Statement from the Second International Nitrogen Conference

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**Human efforts to produce food and energy are changing the nitrogen (N) cycle of the Earth. Many of these changes are highly beneficial for humans, while others are detrimental to people and the environment. These changes transcend scientific disciplines, geographical boundaries, and political structures. They challenge the creative minds of natural and social scientists, economists, engineers, business leaders, and decision makers. The Second International Nitrogen Conference was designed to facilitate communications among all stakeholders in the "nitrogen community" of the world. The Conference participants' goal in the years and decades ahead is to encourage every country to make optimal choices about N management in food production and consumption, energy production and use, and environmental protection. Scientific findings and recommendations for decision makers that emerged from the Conference are presented.**

**KEY WORDS:** nitrogen, N, energy production, food production, nitrogen cascade, ecosystem impacts, environmental protection, nitrogen management, ammonia, $NO_x$, decision makers, reactive nitrogen, nutrient use efficiency

**DOMAINS:** environmental monitoring, environmental management and policy, global systems

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