PROACTIVE APPROACH TO REACTIVE NITROGEN

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ABSTRACT
Nitrogen plays a vital role in food production, and helps to feed the world's ever growing population. At the same time, considerable amounts of nitrogen are lost to the environment in the production of food and energy. This leads to an unbalance in the nitrogen cycle, which results in problems with human health and damage to ecosystems. So far, much of the "nitrogen" policy has been aimed at single nitrogen compounds in single environmental compartments, which can shift the environmental problem to other compounds and other compartments in time. An integrated approach to reduce the negative impacts of nitrogen will lead to a more efficient and cost-effective policy. There is a need for international cooperation in dealing with nitrogen problems on different geographic scales ranging from regional, to continental and global. The Netherlands supports such cooperation and has been involved in promoting international discussion and collaboration on this subject by supporting the International Nitrogen Conferences and the International Nitrogen Initiative, which currently have a strong focus on science. As a next step UNEP could get involved, moving the issue to next stage of the policy cycle.

INTRODUCTION
Reactive nitrogen[1] (N_r) has two very different faces. On the one hand it has a beneficial role in food production, on the other hand food and energy production lead to an unbalance in the nitrogen cycle, which increases the chance of damage to human health and ecosystems (Galloway et al., accepted Biogeochemistry). In response, countries around the world are developing policies to reduce these adverse effects. This paper will show the benefits of a proactive international approach, which is needed to face this challenge in integrated way. It will give a short overview of both the beneficial and adverse consequences of reactive nitrogen and will focus on how the problem is being addressed and the opportunities for a proactive international approach in the future.

BENIFICIAL ROLE OF NITROGEN
Nitrogen, along with carbon and hydrogen, is a basic component of all living beings. Seventy-eight percent of the air we breathe consists of N_2. However, before organisms can use the vast amounts of N_2 contained in the atmosphere around us, it must first be transformed into a reactive form. There are only a few organisms that are able to make this transformation. The availability of N_r therefore controls the productivity of most natural ecosystems. Until the late 19th century biological nitrogen fixation (BNF) was the major source of N_r, along with NO_x created by lightning. Figure 1 shows the growth of the world's population in time together with the total amount of fixed N_r. At the end of the 19th century Nr availability was limiting food production. At that time the Haber-Bosch process was invented, which enables nitrogen fertilizer production from atmospheric N_2, thus limiting the dependency on BNF. At present

[1] Any nitrogen compound that is biologically, chemically or radiatively active (i.e., all nitrogen compounds except N_2).

about 40 percent of the world's population is dependent on the Haber-Bosch process for their food supply (Galloway et al., accepted Biogeochemistry).

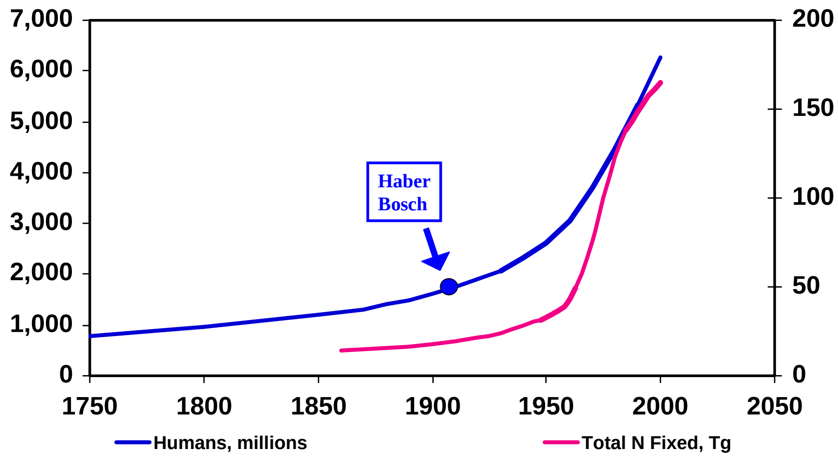


FIGURE 1. The growth of the world population (millions on the left axis) and the amount of reactive nitrogen created by food and energy production between 1750 and 2000 (Tg N on the right axis). (Source: adapted from Galloway et al., 2003)

DISTURBANCE OF THE NITROGEN CYCLE

Nowadays, the amount of nitrogen fixed by natural terrestrial processes is exceeded by human fixation as a result of food production, energy production (NO_x) and industrial activities. Considerable quantities of bioavailable nitrogen are lost to the environment by these processes, disturbing the nitrogen cycle. The rate of denitrification, which converts N_r back to non-reactive N_2, has not kept pace with the increased creation rate of Nr. Therefore Nr is accumulating in the environmental reservoirs (Galloway et al., accepted Biogeochemistry) in those regions of the world where N is used in excess of needs. Some regions of the world (e.g., Africa) do not have enough nitrogen to sustain food production. Nitrate (NO_3^-) in drinking water is harmful to human health, as are excessive concentrations of reactive atmospheric nitrogen gaseous compounds (e.g., NO_2), fine particulate matter (NO_x and NH_3 are important precursors of secondary aerosols) and ozone (in the formation of which NO_x is heavily implicated). Nitrous oxide (N_2O) and O_3 contribute to the greenhouse effect in the troposphere. Too much acidic and nitrogen (NH_3 and NO_x) deposition stresses natural ecosystems through acidification and eutrophication, both of which lead to a loss of biodiversity (Erisman, 2001). Increased flows of N_r into coastal areas lead to oxygen starved zones (UNEP, 2004).

The nitrogen compounds involved are reactive, and can be transformed into one another. A given N containing molecule can in fact contribute successively to different environmental problems, referred to as the cascade effect. This is caused by the fact that reactive forms of nitrogen are often readily soluble in water and/or occur in the gas phase, making them very mobile. Some systems accumulate N_r, thereby slowing down the continuation of the cascade. As systems become saturated, more and more N_r is transported downwind or downstream. N_r is, therefore, both accumulating and dispersing in the environment. Table 1 shows those systems that have a large accumulation potential and those from which N_r is most readily transferred. It also shows where reactive nitrogen is likely to move to, and some potential effects of excess nitrogen within each system (UNEP, 2004).

System	Accumulation potential	Transfer Potential	Links to other systems	Effects potential
Atmosphere	Low	Very high	All but groundwater	Human and ecosystem health, climate change
Agroecosystems	Low to moderate	Very high	All	Human and ecosystem health, climate change
Forests	High	Moderate, high in places	All	Biodiversity, net primary productivity, plant mortality, groundwater
Grasslands	High	Moderate, high in places	All	Biodiversity, net primary productivity, groundwater
Groundwater	Moderate	Moderate	Surface water, atmosphere	Human and ecosystem health, climate change
Wetlands, streams, lakes, rivers	Low to moderate	Very High	Atmosphere, marine coastal systems	Biodiversity, ecological structure, eutrophication, harmful algal blooms
Marine coastal regions	Low to moderate	Moderate	Atmosphere	Biodiversity, ecological structure, fish, eutrophication, harmful algal blooms, hypoxia

TABLE 1. Characteristics of different systems in relation to the nitrogen cascade

As shown in figure 1, N_r creation rates are still increasing and are expected to continue to do so over the next century. Many countries have implemented NO_x and NH_3 control measures. For instance, the Netherlands has reduced NH_3 and NO_x emissions by 45 and 30 percent, respectively, since 1990 (RIVM, 2004). However, without additional policy measures N_r creation rate will increase drastically in the rapidly developing regions of the world. This is mainly caused by increasing welfare and subsequent change in diet and energy demand, combined with the projected growth of the number of people. Figure 2 gives two scenarios about the possible increase in Nr creation rate (Tg Nr/yr) between 1995 and 2050. The left bars show the Nr creation rate due to food production, energy production, and industrial activities) in 1995. The middle bars show Nr creation rate in 2050 scaled to population growth only. The right bars show the Nr creation rate in 2050 scaled by population increases and assuming that all people created the same amount of N_r as the average North American created in 1995 (i.e., ~100 kgN/person/year).

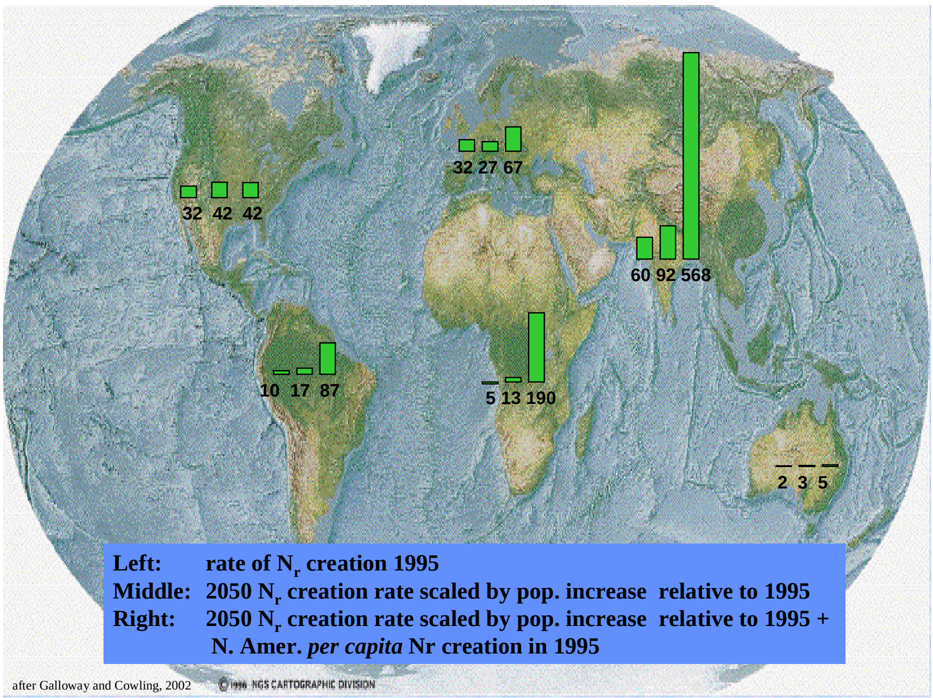


FIGURE 2. N_r creation rate in 1995 and 2050 (two scenario's)

COMBATTING THE PROBLEM

The cascading nature of N_r necessitates an integrated approach to the problems of excess N in the environment. Policy aimed at a single nitrogen compound can shift the problem to other environmental compartments, and in other points in time. An integrated approach to nitrogen-related environmental problems, which takes into account the total N_r cascade, is therefore more effective, and will lead to a more efficient and cost-effective policy (Erisman, 2001, RIVM, 2003).

N_r is related to many elements of environmental policy. It plays a role in nearly all the environmental problems identified in the Dutch Fourth National Environmental Policy Plan as solution-resistant (VROM, 2001). So far, much of the “nitrogen” policy has focused on one aspect of the problem. For instance, the Netherlands has separate policies dealing with animal manure (aimed at controlling groundwater NO_3^-) and NH_3 emissions from animal housing. This lack of integration can lead to suboptimal solutions. From the point of view of the N_r cascade, preventing the formation of N_r as much as possible is the best solution. This limits the total amount of N_r flowing through the cascade and prevents adverse effects.

The spatial distribution of nitrogen is influenced by world trade agreements and commodity exchange. Economic considerations such as preventing distortions in competition or the pursuit of European Union (EU) policies mean that environmental policy in general is increasingly being shaped at an international level. Combined with the fact that N_r is dispersed on a continental and global scale through water and air, calls for an internationally coordinated approach to reduce the N_r emissions.

Already in 1979 the UN/ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) was established to abate air pollution in Europe and North America. For air pollution the CLRTAP has integrated N_r pollution to a large extend in the Gothenburg protocol. The EU has a great deal of legislation relating to nitrogen compounds, which broadly divides into measures affecting water (Nitrate Directive, Urban Wastewater Treatment Directive, etc.) and air (recently national emission ceilings (NEC directive), air quality standards: SO_2, NO_2, O_3, PM etc., and emission standards: large combustion plant, waste incineration, car emissions, etc.). These two policy areas tend to remain separate.

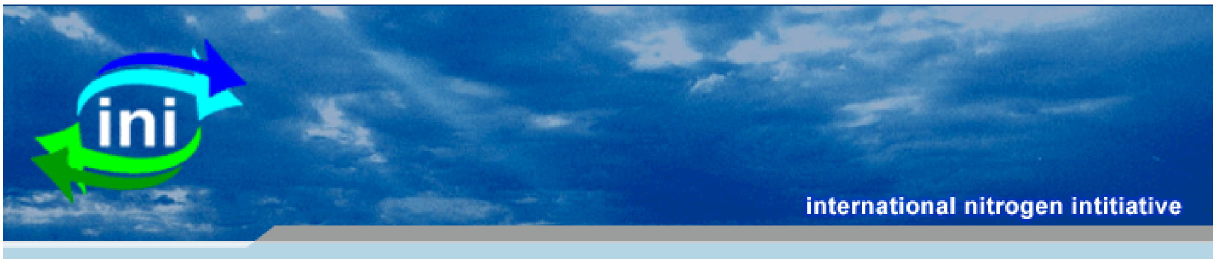
A number of N_r problems related to air pollution are being tackled in an integrated manner in Europe. The reason to integrate was mainly to collect cost savings. The Gothenburg Protocol that was adopted and signed in 1999 set emission ceilings for SO_2, NO_x, NH_3 and VOC for 2010 in order to combat acid and nitrogen deposition on natural ecosystems and the effects of ozone on human health and natural ecosystems. Once the Protocol is fully implemented, Europe’s sulphur emissions should be cut by at least 63%, its NO_x emissions by 41%, its VOC emissions by 40% and its NH_3 emissions by 17% compared to 1990. During the preparation of this Protocol it was estimated that an integrated and cost-effective approach to acidification, eutrophication and ground-level ozone in Europe would halve the costs (Amann et al., 1999). The EU countries later agreed to sometimes somewhat more stringent ceilings in the National Emission Ceilings Directive. Integration in the field of air pollution policy will continue during the coming years. It is intended that when the Gothenburg Protocol and the NEC Directive come up for review in 2005, they will be broadened to deal with the health effects of excessive levels of NO_2 and fine particulate matter (Sliggers, 2004).

INTERNATIONAL COOPERATION

There have been two international conferences on nitrogen over the last six years, with a third conference scheduled for this year. The First International Nitrogen Conference, with a focus on Europe, was held in the Netherlands in March 1998. Three years later, the Second International Nitrogen Conference was held in the USA in October 2001 with a focus on

North America and Europe. The Third Conference will be held in Nanjing, China, in October 2004. The focus of the Third Conference will be on Asia.

The Second Conference established as a goal the development of a sustainable approach to manage nitrogen, and thus be able to provide food and energy to the world, yet minimize release of nitrogen to the environment (Cowling and Galloway, 2002). Towards the realization of this goal, one of the recommendations of the Conference was to establish the International Nitrogen Initiative (INI). By early 2003 the INI was founded. 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. Human impact on the nitrogen cycle differs significantly among the regions of the world. Although most regions have too much N_r, some regions, most notably sub-Saharan Africa has too little. The INI has therefore established regional centers in Africa, Asia, Europe, Latin America, and North America, in order to deal with these differences. The INI is pursuing a three-stage strategy: phase I assessing knowledge on N flows and problems, phase II developing region-specific solutions and phase III implementing solutions. This is described in more detail in box 1.



Phase I: Assess knowledge on N flows and problems:
- What are the controls on N fluxes in the environment?
- How have N fluxes changed due to human action?
- What are the consequences?
- What are the gaps in knowledge?
- How do the answers to these questions vary by region?

Phase II: Develop region-specific solutions:
- What research is needed to fill identified gaps?
- Which solutions can be used to solve identified problems?
- Which tools are required?
- Which areas of expertise are required?
- How do the answers to these questions vary by region?

Phase III: Implement scientific, engineering and policy tools to solve problems:
- Which solution is best for a specific problem?
- What are the barriers to solution implementation?
- Are there economic issues?
- How long will the solutions be effective?
- How do the answers to these questions vary by region?

BOX 1. The phases of the INI assessment with a number of questions that provide examples of the types of information that will be gathered (Source: www.iniforum.org)

One of the main products of the INI will be an assessment of the nitrogen problem. A preliminary assessment will be presented at the 3rd International Nitrogen Conference. This conference will also produce the Nanjing Declaration, which reiterates the current understanding of the nitrogen problem and calls for further cooperation between UNEP and the INI to assess the problem.

PROACTIVE APPROACH
Recently the UNEP Global Environmental Outlook Yearbook 2003 (UNEP 2004) identified the worldwide disturbance of the nitrogen cycle as an emerging challenge, putting the issue on the international policy agenda. A proactive response of policy makers, which anticipates the future disturbance of the nitrogen cycle and takes the entire N_r cascade into account, can save money, time and environmental damage. Three elements have to be considered. Firstly, further assessment of the disturbance of the nitrogen cycle is needed on a local, regional and global scale. It seems appropriate for UNEP to address this issue, as it is the leading global environmental authority and the conscience of the United Nations system. UNEP and other international agencies could work together with the INI to benefit from its expertise and regional structure. Secondly, there are still important gaps in our understanding about the nitrogen cycle, for instance about the potential and extent of denitrification. Countries need to coordinate their research efforts to fill these gaps and save money. Thirdly, countries need to start exchanging experience about dealing with nitrogen problems, which helps them to identify the best solutions.

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