DPSIR reactive nitrogen in the Netherlands

Introduction

Nitrogen is necessary for life as it is a building block in amino acids, proteins and DNA. There is an abundance of *unreactive* (inert) nitrogen on earth (the air exists for 80 % of N_2). The *environmental nitrogen cycle* serves the dynamic exchange of nitrogen between the atmosphere, the terrestrial surface, and the oceans. A small part of the gaseous N_2 is transformed via symbiotic fixation in solid or liquid *reactive* forms (N_r). These nitrogen forms can be taken in by plants, chemically transformed and made available to other organisms. Via processes like nitrogen-fixation, denitrification, biosynthesis, etc. living systems maintain a balance between different reduced and oxidized forms of nitrogen.
However, human activities have enhanced the production of reactive nitrogen and stimulated spreading and accumulation of nitrogen in the environment. This resulted in doubling the total fixation of N globally, and more than tripling it in Europe. Although the artificial fixation of N_2 made production growth and feeding of a growing world population possible, there are great environmental and economical costs that outweigh the direct economic benefits (Sutton and van Grinsven, 2008). The environmental nitrogen cycle has undergone major disruptive changes. Fossil fuel combustion, mineral fertilizers and livestock manure are the major sources of reactive forms of N, like NOx, N_2O and NH_3 nowadays. These forms of N are transformed and transported through the environment (cascading), leading to nitrogen accumulation and all kinds of negative impact on air-, water- and soil quality, biodiversity and human health. European environmental policy should therefore be directed towards reducing the impacts of excess nitrogen. Given the complex nature and widespread origins of the nitrogen problem, an *integrated approach* is needed. On this basis a comprehensive packet of policy measures should be designed, which is aimed at the abatement of unwanted N_r emissions.
The so called 'DPSIR framework' (developed by the Organisation for Economic Co-operation and Development (OECD) and the European Environmental Agency (EEA) in the1990s) is based on such an integrated approach. It is a policy instrument that serves to improve the understanding of the complex and diverse cause–effect relationships of environmental pollution. It also provides a framework for responding to environmental problems through diverse policy measures. According to the DPSIR framework there is a chain of causal links starting with '*driving forces*' (economic sectors, human activities) through '*pressures*' (emissions, waste) to '*states*' (physical, chemical and biological) and '*impacts*' (on ecosystems, human health and functions), eventually leading to political '*responses*' (policy definition, prioritization, target setting, indicators).
An elaborated DPSIR framework, specified for the N-problem in the Netherlands is added in Appendix 1.The changes in the environment are specified for 5 compartments which represent the key societal threats of excess nitrogen (greenhouse balance, air quality, water quality, soil quality, and ecosystems and biodiversity). The mentioned sources, pressures and change- and impact-indicators can provide information regarding the seriousness of the situation, opportunities to focus further research, and points of application for possible solutions. The diagram helps to understand the problem, the causes, the environmental relationships, and accordingly clearifies possible solutions.

Inter-relations

There are multiple linkages among the environmental systems through which the nitrogen molecules move, and among the effects they sort. This phenomenon is called the 'N cascade' (Galloway 1998). Reactive Nitrogen is extremely mobile. Emissions from different sources lead to Nr flows through the different media (air, water and natural ecosystems), thereby exchanging between different Nr-forms, causing multiple harmful effects. For example energy production by fossil fuel combustion results in the formation of NOx. NOx in the atmosphere can increase ozone (O_3) concentrations, increase concentrations of small particles, and increase precipitation of acidity.
Another example is the interaction between acidifying and eutrophying or pollutionary effects of N deposition. Deposition of NO_3, NH_3 or NH_4+ may lead to acidification of the soil. A lower pH can lead to increased leaching of base cations or toxic metals. In addition it can also lead to decreased nitrification, accumulation of litter, stimulation of nitrogen mineralization rates and nitrogen-saturated ecosystems.
Also the complex role of ammonia in the environment is illustrative of the many relations between the different issues in the nitrogen cycle. Emissions of ammonia to the atmosphere can contribute to particulate matter formation, affecting human health. But it can also lead to nitrous oxide (N_2O) formation, contributing to the greenhouse effect and -after deposition- contribute to eutrophication and acidification of aquatical and terrestrial ecosystems. Some of the interrelations are indicated in Figure 1, offering just a limited impression of the complexity of the matter.

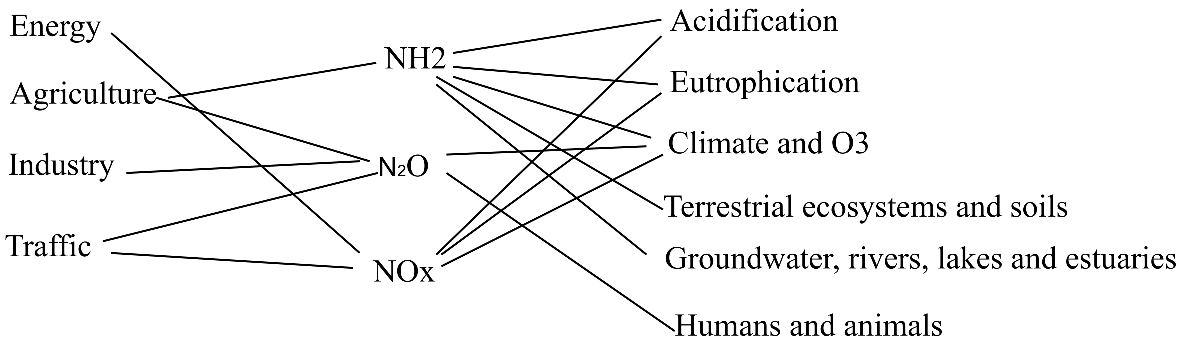

Figure 1. Some interrelations between sources, compounds, and environmental issues/effects (modified and simplified, from Erisman et al, 2003)

External effects

In addition to the mentioned and unmentioned interrelatonships and feedbacks between the different Nr components and the transforming and transporting effects in space and time as shown within the DPSIR-scheme, there are also some external effects that influence the N cycle.

A very important external factor is climate. Wind, radiation and precipitation are important factors for volatilization and chemistry. This might for example effect the conversion of ammonia into ammonium, hence influencing chemical and liquid-air equilibria.

Moreover there are major interrelations and feedback processes with other elements (in particular sulphur and phosphorus), and with the corresponding element cycles. Sulphur emissions, which had increased after WWII as a result of human industrial processes, have decreased since the late nineties due to successful policy measures. However, this is leading to more ammonia to form ammonium nitrates, to higher nitrogen deposition, and to a decrease in cooling effects of sulphur-induced aerosols.

The presence or absence of phosphorus is also very important with respect to the ultimate effects of reactive nitrogen in the environment. Phosphorus is the growth limiting nutrient in many terrestrial ecosystems. The availability of this element is determining the amount of Nr that can be fixed or will leach out. Therefore it will co-prescribe the resulting plant production and biodiversity.

There are also major interrelations with the carbon cycle; these should especially be taken in mind when considering agricultural practices concerning the production of biofuels. Crop production for food or biofuels leads to a different net-exchange of CO_2 , especially if fertilizer is applied and when land use changes (deforestation). N-induced enhanced production results in CO_2 removal from the atmosphere by forests, and sequestration of carbon downstream the N cascade in unfertilized areas. However, this should be weighed against the carbon in fossil fuel saved.

Tools, criteria and solutions

Complex interactions between the nitrogen flows, and high variability of these flows in time and space, complicate the development of efficient abatement strategies. Government policy ended up being fragmentary and focussing on parts of the system, addressing single pollutants, single effects and end-of-pipe solutions. The DPSIR framework and its internal and external interrelations however, make clear that the nitrogen problem needs an integrated overview and computer modeling to bring all the relevant factors together. Since the 1990's integrated computer modelling and decision support systems have been introduced. Examples are the RAINS model for support of acidification abatement strategy in Europe, the Integrated Modeling of Global Climate Change (IMAGE), and NITROGENIOUS, the nitrogen decision support system (Erisman a.o., 2002). The models and support systems are based on different components (building blocks), which are separate models themselves. Inputs for these submodels are indicators like emissions and fluxes. Moreover, important inputs are also socio-economic parameters like production volumes, or fuel and energy use, and gross domestic product (GDP) or employment rates per sector. These can be defined on the basis of average levels or within certain margins, referring to different regions or future scenario's. Abatement options can be part of the modeling, and the impacts on certain model parameters can be predicted. A n integrated decision support system will finally provide the necessary overview and show the consequences of different options on various issues to politicians and decisionmakers. It provides insight in the different contributing emissions to soil, air and water, produced by the relevant economic sectors and activities, and the resulting environmental consequences. And it will also show the the socio-economical consequences of different abatement strategies, in terms of expected income or prosperity. Results from simulations indicate that the nitrogen problem can be solved with large social and/or economic consequences. When very little environmental progress is made, the growth in the GDP is high. However, very big environmental progress can be made both with very high and very low growth in GDP (Erisman a.o., 2002). Ultimate aim is to solve the nitrogen problem while incurring minimal economic costs and societal impacts. Economic and social criteria, which are part of the definition of sustainable development, are therefore, in addition to environmental critera, criteria that play an important role in ranking different abatement options.

Stakeholders and further implementation issues

Stakeholders in the nitrogen problem are politicians, consumers, industrialists and farmers. The principle aim of the industrialist and the farmer is to make money. The politician's aim is to have a good image, and the ultimate aim of the consumer is to stay happy or increase his happiness. The latter increases when the environmental conditions and/or the economic situation improve. These are the stakeholders and their ultimate motives as they are presented in playing the Nitrogenious Game. In reality stakeholders comprise of large groups of citizens, in developed and developing countries, who are dependent on enough available food and energy. They need to live in areas where air- and waterquality sustain their health. Policy- and decisionmakers are responsible for making at least these minimum subsistance needs available to people. On the other side there are farmers and businesspeople who need to make a living without compromising that of others.

However, at present stakeholder- and public awareness of the global nitrogen challenge is still very low. The complexity of the matter is a barrier. In order to improve awareness it is important to distil easy messages and use aids like for instance Nitrogenius gaming and the footprinting approach. The strongest message to the public might be that there are substantial health benefits to be gained by keeping consumption of animal products within recommended dietary limits. This provides the opportunity to improve personal health and protect the environment at the same time.

Apart form focussing on specific stakeholders and individual responsibility, there should also be a focus on international cooperation and institutional development. The integrated approach to control all forms of damaging reactive nitrogen is asking for an increased level of institutional cooperation. This is necessary in order to push the research agenda. There is still great uncertainty with respect to NH_3 emissions, and with respect to national balances. There are many doubts about the effectiveness of different measures, for instance because of trade-offs with extra energy use or other emissions. International cooperation is also needed to come to agreements on N production ceilings within acceptable costs and conditions for society. The setting of production ceilings should be based on insight in the cascade of effects in the different compartments and to the different target groups.

Nitrogen in the Netherlands

A common European policy objective to increase food production certainly had its effects in the Netherlands. Supported by public investment, farmers increased their agricultural output significantly in reponse to such policies. This resulted in mechanization, reliance on inorganic fertilizers and pesticides, the cultivation of marginal land, and production efficiency improvements. The EU Common Agricultural Practice (CAP) and Dutch national policy stimulated intensification of agricultural production ever since. Because of its agricultural focus, small area and dense population, intensification and production efficiency in the Netherlands have lead to very high production levels per hectare. As a result the Netherlands now has a relatively high N status, because of very high fertilization rates (more than 400 kg/ha/yr (Erisman and Monteny, 1998).

Policy measures to decrease NH_3 emissions were primarily aimed at keeping N in the manure until it is incorporated into the soil (manure injection systems). Also investments in housing and air filters in cowsheds are being supported by the government. Other measures concerned the introduction of a system of mineral bookkeeping, the reduction of the use of inorganic fertilizers, and the introduction of milk production quota, which has a positive side-effect with respect to fertilizer use.

Although there has been a significant reduction of the nitrogen surplus in the Dutch agricultural sector the use of N is still very inefficient. However, this is not a typical Dutch problem. The gap between input and output of N can be up to 40 % (Oenema et al., 2007). This is called 'the Enigma of the Nitrogen balance' (Allison, 1955). It is suspected that denitrification is the most important process that can explain this gap. Also organic nitrogen, emissions of amines and ammonia emissions might play a role. Nitrogen use efficiency decreases with higher inputs. Therefore, many research efforts and measures are directed towards improving the efficiency of nutrient cycling at farm level.

The recent EU-policy and transition of the CAP aims at the decoupling of the payments and bring them in compliance with environmental legislation ('cross-compliance'). This is an important movement towards decreasing the environmental impacts of agriculture in the Netherlands.

In 2011 the Dutch government has introduced a new nitrogen policy which applies to the environment of the internationally qualified Natura 2000 areas. It is called the 'Programmatic Approach nitrogen' (PAS). The approach aims at reducing emissions of nitrogen and bring a halt to the deterioration of the quality and disappearance of specific types of rare habitats. The seriousness of the nitrogen problem is calculated on a regional and local scale. On the basis of these calculations lies a computer model which incorporates data and produces maps with regard to nitrogen emission and deposition. This information is combined with specific information on maximum deposition requirements of the qualified habitats. The outcome of the approach is that farmers in, or in the vicinity of these nature areas, sometimes need to take measures to reduce emissions in order to improve the quality of nature. In this way also room for additional production development in the area and individual agricultural business development is calculated.

Nitrogen in Africa.

It is expected that tropical regions will receive the most dramatic increases in N_r inputs over the next few decades (Lara et al, 2001). The tropics are home to the bulk of terrestrial and freshwater biodiversity. Given that elevated N_r inputs result in biodiversity losses in higher latitude ecosystems (Phoenix et al, 2004), the projected trends are cause for concern for the situation in Africa.
Tropical forests and savannas have always been considered as relatively insensitive to N effects, as many of these systems are limited by phosphorus. However, most of the additional nitrogen inputs to tropical systems will be lost from the system to the water and air. The consequences will be a.o. acidification and decreases in carbon storage in moist tropical forests (Matson et al, 1999). Another problem is that a initial low level of fertilizer inputs may lead to N and P depletion and consequently to land degradation. However Bouwman et al (2010) indicates that in all future scenarios for Africa land degradation rates by nutrient depletion are reduced or halted. As a result, however, will N and P nutrient soil balances increase. Contributing factor is also the relatively high biological N_2 fixation rates in tropical and savanna areas in Africa. Massive increases in the flows of N and P are expected in all developing countries, even under a proactive N scenario, while in industrialized countries with a proactive approach the N and P use in agriculture can be controlled (Bouwman et al, 2010).

Conclusion and future needs

There are several sustainability issues, and nitrogen is merely one of them. However, it is an important one, not just for the Netherlands, where the intensity of the agriculture and population density leads to exceptionallly high impact figures, but also for Africa and all over the globe, because of transboundary effects and specific interactions.The impact of the human induced accumulation and environmental spreading will still be great in the future, according to prognoses from different scenario's. Therefore missing links in knowledge should be addressed, and concrete policy options should be worked out to combat the negative effects and balance the global nitrogen cycle.

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