Workshop: The Causal Relations of Nitrogen in the Cascade,
21-23rd Nov 2005, Braunschweig - Germany

Summary and Conclusions of the workshop

Summary

During three days a workshop was organised on the causal relations of nitrogen in the cascade. The workshop location was the city of Braunschweig in Germany and one of the local organisers was the 'Forschungsanstalt für Landwirtschaft' (FAL). Annex 1 shows the programme of the workshop, which was jointly organised with the Convention on Long-Range Transboundary Air Pollution (CLRTAP) of the UN-ECE. During different sessions the state of knowledge was presented on the three main parts of the causal chain: emissions, transport and deposition and effects. In total about 40 participants were present at the workshop. This document summarizes the results and conclusions of the meeting and lists the draft recommendations.

Introduction to the workshop topic

Excess nitrogen has effects on a wide range of issues and the environmental policy responses to-date have been equally diverse. Atmospheric emissions of NO_x and NH_3 and their impacts on acidification, eutrophication and ground-level O_3 (NO_x emissions) are being addressed under the Gothenburg Protocol of the UNECE Convention on Long-Range Transboundary Air Pollution, as well as under the EU National Emissions Ceilings Directive (NECD). The agreements are now also beginning to address the abatement of atmospheric aerosol concentrations. These issues are, however, being treated separately from the impact of N on greenhouse gas fluxes, either as N_2O emissions, or the interactions of N with CO_2 and CH_4 fluxes. The Kyoto Protocol of the UN Framework Convention on Climate Change provides the focus for abatement of these impacts, although the emphasis is very strongly on carbon. The impact of N on eutrophication of marine areas is from a European perspective handled under a series of regional marine conventions (Black Sea, the Mediterranean Sea, the North-East Atlantic, including the North Sea, and the Baltic).
In relation to water quality, the EU Water Framework Directive (WFD) links to wider issues of land-use management. However, at present, the links to atmospheric N fluxes and impacts are not fully made. Furthermore, policies on food production and subsidiaries are not linked with the environmental issues and are separated from energy production and use.

Objective of the workshop

The objective of this workshop was to assess the state of knowledge of the different causal relationships of nitrogen, Better understanding and decreasing the uncertainty in causal relationships will form the basis of improved and more integrated policies.

Questions that were addressed included:

- What is the state of knowledge on cause-effect (DPSIR) relationships?
- How well do we understand the different parts of the causal chain?
- How good can we model them/on what scale, and are these suitable for Integrated Assessment Modelling?
- What is needed in terms of research, experiments, models, etc.?

Conclusions

Nitrogen plays an important role in many environmental issues. In most cases nitrogen is not dominant, but an important factor. Human creation of reactive nitrogen and addition to the bio-geochemical cycle has led to increased exposure to air pollutants (NOx, particulate matter, organic nitrogen containing toxics), water pollution with nitrates, acidification, eutrophication and changes in species composition in terrestrial and aquatic ecosystems and to changes in climate and the stratospheric ozone layer. The workshop produced a tabular overview of the current knowledge and understanding of nitrogen related air pollution effects in Europe (Annex 2). In general there is reasonable to good evidence for the nitrogen-related effects. This means that we have empirical relations between changes in the nitrogen cycle and the effects. The level of understanding, however, and the translation of processes into models are not well developed, because of the complexity of the systems and the many interactions. Therefore, there are no clear indicators and thresholds to be used in integrated assessment models. The two exceptions to this are the (dynamical) models of critical loads for N deposition to semi-natural vegetation in NW Europe and the models for fresh water ecosystems. The level of understanding is limited of the drivers in the different systems, the different roles of NH_4 and NO_3, feedback mechanisms and the link to other bio-chemical cycles.

Emissions of the main single sources of reactive nitrogen can be quantified and modelled. Agriculture is the most complex sector for emissions of nitrogen compounds into the environment, not only with regard to understanding of the processes leading to (net) production and emission of these compounds but also with regard to options, costs, and efficiencies for abatement. Agriculture is also the most important sector for ammonia emissions and contributes with a similar amount of nitrogen as that emitted as nitrogen oxides from energy sources (Lövblad et al., 2004). Agricultural sources emit about 10% of the GHG in Europe (CH_4 and N_2O) or about 66% of the N_2O emitted in Europe (EEA, 2005). Opportunities for ammonia, nitrous oxide and nitrate abatement include nutritional measures, animal housing and manure storage design, fertilization practices and cropping and land use planning (ECCP, 2002; ECCP, 2003; UN-ECE, 2005). “Industrial/new thinking”, taking the Life cycle into account, is necessary for effective abatement measures as part of more integrated policies. As nitrogen is ‘cascaded’ through various stages in agricultural production systems before its eventual emissions, measures aiming at mitigation in an earlier stage will have (positive or negative) effects on emissions at later stages. These interactions are not always simple and have to be evaluated using a mass-balance model (EMEP, 2003). The generalisation (time and space) is an issue, especially for the sources in agriculture and for the diffuse sources, which vary strongly in time and in space.

Nitrogen is easily cascaded through the different compartments of the environment, where many changes in its oxidation state might occur. Furthermore, there are several places where nitrogen can be stored and both the storage capacity as the storage time might differ. Examples of stores include the soil as organic nitrogen, in forests where nitrogen is cycled through tree uptake, leaves, litter, soil, etc., in lake sediments and in rivers or in the marine area. Losses of nitrogen from the cascade eventually occur after de-nitrification (as N_2). There is a need to quantify the reactive nitrogen stores, delay times and losses in the cascade. Transport and the atmosphere – biosphere exchange of nitrogen modelling faces this issue, together with, temporal and spatial scales and interactions (emission-concentration-deposition, chemistry). There is a lack of observations to understand the different processes determining the transport issues and to verify the models for quantification.

Recommendations

Effects:

1. Gather and make available sources of available monitoring and modelling data for use in development of models and indicators/criteria
2. Clarify further the major effects, intermediate parameters together with [harmful] endpoints and
3. Compile existing dose response relationships from case studies and extensive monitoring programmes and make available for the community
4. Bring together models and observations for further validation and explore potential for applications at large geographical scales
5. The main priorities for research needs to fulfil near future policy needs were identified as:

(i) Continuation of **model development** to link soils and biodiversity to assess past and future trends in species change at the regional level under different deposition scenarios. This will require an **expansion of monitoring and experimental work** to provide the data for process understanding, model development and testing.
(ii) quantification and development of models which enable the **interactions** with other drivers (e.g. ozone, greenhouse gas emissions, climate change including elevated CO_2, management) to be able to interpret spatial and temporal trends in ecosystem compartments and forecast for the future
(iii) quantification of **feedbacks** between ecosystem components. This needs to include changes in diversity of plants (a particular focus is needed on mosses and lichens due to their sensitivity), fauna (macro and micro) and soil microbes and include implications for biogeochemical functioning and ecosystem resilience to stresses
(iv) there is a need to separate the effects of **oxidised vs. reduced** nitrogen for all ecosystem components
(v) development of methods to build an **Integrated Assessment Model** stepwise to advise on emission reduction requirements and develop methods for upscaling
(vi) to identify the major paths in the **causal chain** of emissions, atmospheric transport and effects on specified receptors

Emissions:

1. There is need for a larger pool of experimental observations of high quality close knowledge gaps and to be used for statistical analyses and model validation
2. There is the need to bridge the scale between models with clear boundary definition and upscaling from the micro-scale to the regional scale
3. There is the need for relevant management data and information on abatement options
4. There is the need for integrated assessment, both of different environmental issues and socioeconomic aspects within a model across the scales
5. There is the need for innovative thinking with respect to agricultural production and regional mitigation options

Transport and surface exchange:

1. There is need to get more insight in missing and/or poorly quantified sources
2. There is the need to come to catchment scale N budget studies

3. There is the need for more insight in emission-concentration relations and their trends
4. There is the need for studies on the consequences of upscaling and downscaling the nitrogen cycle
5. There is the need for incorporate recently identified mechanisms into regional models

Detailed working group reports are presented in annex 3.

Annex 1: Programme of the Workshop

Workshop
The Causal Relations of Nitrogen in the Cascade
21 - 23 November 2005, Braunschweig - Germany

Programme

Monday 21 November

09.00 - 10.00	Registration + Coffee
Opening Session	
10.00 - 11.00	Welcome and introductory presentations: Jan Willem Erisman (Chair COST Action 729), Matti Johansson (UNECE), Michel Sponar (EU), Ulrich Daemmgen (FAL).
Session:	*General introduction on the topic*
11.00 - 11.45	***Invited presentation***: Nitrogen Saturation of Terrestrial Ecosystems: A Revised Framework - *Brigit Emmett*
11.45 - 12.30	***Invited presentation***: Adverse Impacts of Elevated Nitrogen Inputs on Ecosystems: An Overview - *Wim de Vries*
12.30 - 14.00	Lunch
Session:	*Emission*
14.00 - 14.30	Comprehensive Emission Inventories as Tools for Policy Advice - *Ulrich Daemmgen*
14.30 - 15.00	Denitrification and Nitrous Oxide Emission in Agricultural Soils - *Peter Kuikman*
15.00 - 15.30	Wetlands as Hot Spots for Greenhouse Gases in Glacial Drift Areas - *Jurgen Augustin*
15.30 - 16.00	Coffee break
16.00 - 16.30	Understanding and predicting Nitrogen Fluxes at the Farm Scale - *Jorgen Olesen*
16.30 - 17.00	From Land Use to Farm Types: Availability and Potential of Agricultural Information at European Scale - *Adrian Leip*
17.00 - 17.30	Indirect N_2O Emission due to Atmospheric Nitrogen Deposition - *Albert Bleeker*

19.00 - ??.??	Workshop dinner at the Courtyard by Marriott Hotel

Tuesday 22 November

Session: *Transport - Exchange - Deposition*

09.00 - 09.30	Soil - Atmosphere N_2O and CH_4 Exchanges in Mediterranean Sclerophyllous Woodlands as affected by Global Change - *Simona Castaldi*
09.30 - 10.00	The Role of Atmospheric Nitrogen in the Baltic Sea Eutrophication - *Anita Lewandowska*
10.00 - 10.30	Consequences of N deposition on biosphere-atmosphere exchange of N and C trace gases in forests: results and modelling studies - *Klaus Butterbach-Bahl*
10.30 - 11.00	Coffee break
11.00 - 11.30	Land Atmosphere Exchange of Reactive Nitrogen Species in Europe - *Mark Sutton*
11.30 - 12.00	Estimation of Nitrogen Flux between the Atmosphere and Aquatic/Terrestrial Ecosystems in Hungary - *Szilvia Kugler*
12.00 - 12.30	Trends of Nitrogen in Air and Precipitation in Europe - a comparison of EMEP Model Results and Observations - *Hilde Fagerli*
12.30 - 14.00	Lunch

Session: *Effects*

14.00 - 14.30	Does Organic Nitrogen play a significant role in the Nitrogen Cycle of Temperate Ecosystems? - *Lutz Breuer*
14.30 - 15.00	Separating the effect of Pollution, Climate Change, Wildlife and Forest Management on Forest Production and Ground Vegetation Biodiversity - *Salim Belyazid*
15.00 - 15.30	Relation of Nitrogen Deposition and Stand Structure in Northwest German Forest Ecosystems - *Henning Meesenburg*
15.30 - 16.00	Coffee break
16.00 - 16.30	Modelling Effects on Biodiversity by Eutrophication and Acidification with BERN - *Philipp Hubener*
16.30 - 17.00	Effects of different Forest Conversion Practices on Nitrogen Fluxes in an N-saturated Spruce Forest Ecosystem - *Nicolas Bruggeman*
17.00 - 17.15	Coffee break
17.15 - 17.30	Short Introduction on the Workgroup sessions
17.30 - 19.00	Workgroup sessions
19.00 - 20.30	Posters (drinks + snacks)

Wednesday 23 November

09.00 - 10.00	Feedback from Workgroup sessions
10.00 - 10.30	In search of efficient Air Pollution Strategy for Europe; the role of Nitrogen - *Zbigniew Klimont*
10.30 - 11.00	Coffee break
11.00 - 11.30	Why did Nitrogen Management fail within Various Policy Arenas - *Peringe Grennfelt*
11.30 - 12.00	Work on Nitrogen Effects in CLRTAP - *Till Spranger*
12.00 - 12.30	Conclusions, Greetings and End of Workshop - *Jan Willem Erisman*

Poster presentations

Session: Emission

- Impact of nitrogen fertilization on loss of nitrogen from agricultural system - *Triin Teesalu*
- Farm-N internet model of farm N flows - *Nicholas Hutchings*
- Projection of NO_x, N_2O and NH_3 emission limits at regional level in Poland for fulfilling national obligations of international conventions and EU NEC directive - *Janina Fudala*

Session: Transport - Exchange - Deposition

- Investigating possibilities for a local ammonia policy - *Willem Asman*
- Atmospheric nitrogen concentrations in Finland: trends vs. emission reductions - *Tuomas Laurila*

Session: Effects

ANNEX 2: Summary of current knowledge and understanding of nitrogen air pollution related effects in Europe (excluding agricultural systems)

Effects	**Evidence for effect**	**Level of processes understan ding**	**Modelling**	**Do we have an indicator**	**Critical value / indicator**	**Spatial / temporal scale**	**Gaps**	**Comments**
	--,-,+,++	--,-,+,++		MapMan = Mapping Manual				
Terrestrial ecosystems, species diversity								
Semi-natural vegetation (semi-temporal vegetation, natural forest non-productive)	++	+	Steady state CL empirical +, Dynamic +/-	CL empirical and steady state mass balance approaches in MapMan, -; directives, red lists etc qualitative available	For CL empirical and steady state mass balance models; No quantitative level for habitat protection, -	Mostly NW-Europe and N-America; Temporal effect depends on whether inputs are acute or chronic	Regional, EECCA missing	Dynamic modelling in progress, applications pending, validation needed
Soil microbes	+	-	--	--	--	--	Effects of changes in diversity on ecosystem functioning and resilience	
Faunal (macro &	+	+/- (- For	-	Quantification	--	--	Need to	

micro)		processes)		missing			identify indirect effects (e.g. food chain) as well as direct	
Soils quality								
Nutritional balance	++	+	+	+ CLs MapMan for forests	+ MapMan	Depends on load		Only known for forests, perhaps crops; need to expand for other species
Acidification of soils	++	++	++	+ Bc/Al, pH, [Al]	Abundant	Slow, decades-century; large spatial impact		
Production of forests	+ for growth	+	+	+ yield,	Effect is positive	Spatially complex, temporal quick		Interaction with other drivers
Production of semi-natural vegetation	+/-	+/-	+/-	Yes, qualitatively	-	Temporal quick		Many systems used for low intensity production. Also relevant to quantify carbon sequestration
Sensitivity to events (frost, drought, diseases, management?)	+	+	+/-	Case studies	-	Years to build up susceptibility		Trees and vegetation; case studies on harmful effects on trees (risk)
Waters								
Surface waters	++	++	Many for acidificatio n, links exist to biology	For acidity: pH, ANC; also for eutrophication	Acidification: yes; for N varies between countries linked to WFD	Timing slow. More data available for NW Europe	Regional gaps in knowledge, data mainly NW-Europe	Also biological

Marine	++	+						Insufficient expertise in the group to discuss fully
Climate								
Nitrous oxide	++	+	++	CO_2-equivalents	Does not exist			
Methane	+/-	+/-	+/-	CO_2- equivalents	Does not exist		Data from more regions, soils and habitats	
Carbon dioxide flux from soil organic matter	+/-	+/-	-	CO_2	-	Direct effects are quick. Indirect effects through change in litter quality are slow	Reported effects on decomposition need to be fully tested	
Fine particles	+	+	+	-	-			Linked to other secondary aerosols

Note: Human health issues including nitrate in drinking water, air pollution, ozone and NOx, fine particles and pollen production were all issues beyond the expertise of the group and were not discussed.

Annex 3 Detailed working group reports.

'Effects' Working Group

Introduction
An assessment of current knowledge, process understanding, availability of indicators and models and gaps in knowledge was carried out by the group and is presented in ANNEX 2 in tabular form. Here, a summary is provided together with six priority recommendations including priority areas for research.

Species change
The evidence for effects of nitrogen on species diversity was separated into semi-natural vegetation, faunal and soil micobial communities. With respect to semi-natural vegetation the state of knowledge was agreed to be well known with a reasonable understanding of underlying processes. Dynamic models are under development and some are now available for testing. Steady state empirical loads and mass balance approaches have been quantified for a variety of ecosystems/receptors but we need further refinement of impact criterion and thresholds when unwanted changes occurs. There is also need for intermediate targets/changes which will enable attribution of change and path to be identified Gaps in knowledge were agreed to be data availability outside NW of Europe. A major need for improvement is the continued development of dynamic models which link soils, waters and biodiversity. With respect to effects on fauna and soil microbes, there is some evidence for effects but underlying processes are not well understood. There are few indicators and models and further work is required particularly to understand the implications of changes in food chains and ecosystem functioning. With respect to species change in general, feedbacks from species change to biogeochemistry fluxes and ecosystem functioning is a longer term aim but work needs to be initiated now.

Soils
With respect to soil quality, evidence of changes which result in nutritional imbalances and soil acidification were thought to be well known Underlying processes and model availability were thought to be reasonable and well known respectively. Indicators of nutritional imbalance are available in the Mapping Manual together with chemical criteria, however this is only well known and tested for forests systems. For soil acidification, effects are well known with well-tested models covering major impacts. For impacts of nitrogen on productivity of forests, there is evidence of effects and process understanding but patterns are spatially complex due to interactions with other drivers (e.g. climate, ozone, management). Impacts on production in semi-natural vegetation is far less well known or quantified. There is evidence for increased sensitivity to events such as drought and disease but this is generally based on case studies with some examples of habitat specific models but there is a need for this to be expanded.

Waters
There is good evidence for impacts on surface waters together with process understanding and a variety of well tested models with some links to biodiversity and production effects. Most common criteria are pH and ANC with country specific limits for eutrophication linked to the Water Framework Directive. For marine systems, there is good evidence of effects and some understanding of processes but models beyond estuary models are required together with improved process understanding.

Climate
Effects of nitrogen on nitrous oxide emissions are well quantified and understood with models available. For methane, the effects are more variable and less well understood with a need for more data and models which are relevant for different soils/habitats/regions. Effects of

nitrogen on soil organic matter decomposition and CO_2 flux (effects on carbon fixation by vegetation are included in production above) is an area of debate which requires further quantification and model development. Effects for all three gases can be expressed as CO2-equivalents. Particulates were not discussed, but it was recognised that nitrogen contribute to the formation of fine secondary particulate matter which affect the radiative forcing at large-scale geographical scales.

Materials, Human Health and Visibility
We acknowledged that nitrogen pollution also contributes to the corrosion and soiling of materials but did not have expertise to further discuss this issue. The effects have been monitored and modelled on test sites over Europe. In addition, the human health issues are clearly of importance but were beyond the expertise of the group. Visbility issues have been well studied in N America but they have not been a focus for policy development in Europe.

Generic issues
- The differential effects of oxidised and reduced nitrogen for all ecosystem components effects (soils, waters and vegetation) is poorly quantified.
- Information is biased towards NW Europe with a need to expand observations, process understanding and model applications to Central and Southern Europe.
- Timing of effects were thought to be dependent on whether N inputs where acute or chronic (i.e. changes could be fast if inputs increased quickly to very high levels) but are generally quicker for vegetation than for soils and waters.
- Interaction of N effects with other drivers (climate change including elevated CO2, management, ozone) and feedbacks are poorly known at present

Recommendations:
(1) gather and make available sources of available monitoring and modelling data for use in development of models and indicators/criteria
(2) clarify further the major effects, intermediate parameters together with [harmful] endpoints and
(3) compile existing dose response relationships from case studies and extensive monitoring programmes and make available for the community
(4) bring together models and observations for further validation and explore potential for applications at large geographical scales
(5) The main priorities for research needs to fulfil near future policy needs were identified as:
(i) Continuation of **model development** to link soils and biodiversity to assess past and future trends in species change at the regional level under different deposition scenarios. This will require an **expansion of monitoring and experimental work** to provide the data for process understanding, model development and testing.
(ii) quantification and development models which enable the **interactions** with other drivers (e.g. ozone, greenhouse gas emissions, climate change including elevated CO2, management) to be able to interpret spatial and temporal trends in ecosystem compartments and forecast for the future
(iii) quantification of **feedbacks** between ecosystem components. This needs to include changes in diversity of plants (a particular focus is needed on mosses and lichens due to their sensitivity), fauna (macro and micro) and soil microbes and include implications for biogeochemical functioning and ecosystem resilience to stresses
(iv) there is a need to separate the effects of **oxidised vs. reduced** nitrogen for all ecosystem components
(v) development of methods to build an **Integrated Assessment Model** stepwise to advice on emission reduction requirements and develop methods for upscaling
(vi) to identify the major paths in **causal the chain** of emissions, atmospheric transport and effects on specified receptors.

Working Group on Emissions and Policies

Peringe Grennfelt (chair), Adrian Leip (rapporteur), Jurgen Augustin, Klaas van der Hoek, Sabine Augustin, Ulrich Daemmgen, Janina Fudala, Nicholas Hutchings, Zbigniew Klimont, Peter Kuikman, Jorgen E. Olesen, Michel Sponar

Introduction

Agriculture is the most complex sector for emissions of nitrogen compounds into the environment, not only with regard to understanding of the processes leading to (net) production and emission of these compounds but also with regard to options, costs, and efficiencies for abatement (UN-ECE, 2005).
Agriculture is also the most important sector for ammonia emissions and contributes with a similar amount of nitrogen as that emitted as nitrogen oxides from energy sources (Lövblad et al., 2004). Agricultural sources emit about 10% of the GHG in Europe (CH_4 and N_2O) or about 66% of the N_2O emitted in Europe (EEA, 2005). Opportunities for ammonia, nitrous oxide and nitrate abatement include nutritional measures, animal housing and manure storage design, fertilization practices and cropping and land use planning (ECCP, 2002; ECCP, 2003; UN-ECE, 2005). As nitrogen is 'cascaded' through various stages in agricultural production systems before its eventual emissions, measures aiming at mitigation in an earlier stage will have (positive or negative) effects on emissions at later stages. These interactions are not always simple and have to be evaluated using a mass-balance model (EMEP, 2003).
Therefore, the working group on emissions and policies focused on the agriculture sector; expertise of the participants covered all aspects from detailed agronomic and process understanding to integrated assessment and EU legislation.

Recommendations

The working group on emissions and policies saw urgent need for future research in five main scientific areas: experimental research, data collection, model development, increasing efforts in trans-disciplinary research and a paradigm shift for agricultural abatement options.

6. **There is need to a larger pool of experimental observations of high quality to close knowledge gaps and to be used for statistical analyses and model validation**

The complex interactions between various processes involved in agricultural nitrogen emissions are far from being understood, large knowledge gaps persist, e. g. the onset of nitrate leaching in nitrogen-saturated systems, the impact of litter quality on microbial activity, etc. Measurements are needed to understand the processes and to be able to statistically derive specific emission factors for conditions and regions that so far are under-represented, such as central-eastern Europe and the Mediterranean. Mass flux budgets at the farm scale, for the soil profile or at the regional scale, cannot yet be closed; this implies the need to continue to measure also inert components such as di-nitrogen, to obtain additional constraints for a closed budget. Research on interactions and effects of other compounds, such as carbon and phosphorus, must be included. Process models will be able to deliver policy-relevant indicators combining the effect of different but simultaneously acting drivers, but a robust dataset for thorough model validation is still lacking. For all purposes, however, highest quality of experimental data including metadata is a prerequisite which should be emphasized and promoted, for example, in emission Guidelines.

7. **There is the need to bridge the scale between models with clear boundary definition and upscaling from the micro-scale to the regional scale**

The high complexity of processes leading to emissions from agriculture and the high non-linearity of effects makes upscaling of models and results obtained at the plot or farm scale one of the biggest challenges in the next future. To avoid the risk of oversimplified models leading to biased messages or being unable to react to unforeseen situations, it is necessary to work at the 'micro-level', to cross-check models at various complexity, and to bridge information obtained at various scales and with different methodologies, e. g. from bottom-up and top-down approaches. Boundaries must be strictly defined to enable models to communicate; for example, nitrogen must be taken up by transport models where they are emitted from the farm or ecosystem model and deposited where it can be received by an ecosystem or landscape model. For each 'box' mass conservation must be ensured.

8. **There is the need for relevant management data and information on abatement options**

One of the biggest obstructions for reliable estimates of nitrogen fluxes from agriculture at the European scale is the complete lack of comprehensive and harmonized management data. Information on animal housing, feeding and manure management systems, fertilizer and tillage practices, cropping and irrigation patterns are fundamental for depicting the environmental impact of agriculture in a realistic way. Technical abatement options for agriculture are still poorly defined, in particular the quantification of the costs involved and how they change with farm size.

9. **There is the need for integrated assessment, both of different environmental issues and socioeconomic aspects within a model across the scales**

The relationship between nitrogen and the environment can be described as being multi-source, multi-pollutant and multi-effect. The answer were multi-policies. These need to be integrated in order to being able to profit from opportunities of synergies, avoiding swapping effects and for being realistic and cost-efficient in assessing and realizing mitigation measures. Integration implies also to be proactive with respect to future societal demands. A strong driver for the agricultural sector and a large potential for mitigation (as technical options are limited) is the behavior of the consumers. Assessment of agriculture without considering the socio-economic dimension can never give the whole story. Therefore, the development of detailed integrated assessment tools for the agricultural sector is urgently required. These tools must also be able to reflect (externally driven) structural changes in agricultural systems and serve as tools for scenario calculation and communication ("smart") to ensure the socio-economic acceptance.

10. **There is the need for innovative thinking with respect to agricultural production and regional mitigation options**

We need new thinking and design in agriculture to improve environmental performance; reduce emissions and increase production efficiency at the same time. In order to achieve that we suggest verifying what can be learned from best industrial operation practice - industrial thinking. Potentially a bit controversial term "*Industrial* *thinking*" is understood here as a vehicle for optimizing the flow of material and the use of resources in agricultural systems (cascading of primary resources) and must not be confounded with an industrialized agriculture. The optimum system will neither be the most intensive (with high negative effects on other policies, e.g. animal welfare) nor the most extensive one (where many mitigation measures are not applicable). Rather, it must be found by internalizing the costs for environmental effects and make (omitted) emissions valuable. The extension of the IPPC directive to cattle farming and introducing new thresholds for pig and poultry farms, as foreseen in the Thematic Strategy on Air Pollution, will be a first step. The regional assessment of abatement will be essential in order to identify conflicts with other policies and to prioritize measures.

References

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Working Group on Transport - Exchange - Deposition of Nitrogen
Mark Sutton (chair), Albert Bleeker (rapporteur), Klaus Butterbach-Bahl, Hilde Fagerli, Robert Gehrig, Laszlo Horvath, Andreas Krein, Silvia Kugler, Joakim Langner, Tuomas, Laurila, Anita Lewandowska, Attilla Machon, Kjetil Torseth, Zdenek Zelinger

Introduction

The working group on transport-exchange-deposition of nitrogen addressed this topic by making an inventory of important and/or missing issues by means of a brainstorming session. A complete list of the issues brought up during this session is given in Annex 1. The brainstorming session was followed by a prioritisation of the different items, were the criteria for prioritisation were:

1. scientifically uncertain (current scientific results would lead to misleading policy development);
2. influencing policy implementation (e.g. compliance assessment) and
3. integrating between phases of the nitrogen cascade

Based on the brainstorm session and the subsequent prioritisation, the following five main points of attention for future research were identified by this working group.

11. There is need to get more insight in missing and/or poorly quantified sources

From the brainstorm session it was recognized that there is need to get more insight in some missing and/or poorly quantified sources. Sources that were mentioned in this context are organic nitrogen and nitrogen emissions from water surfaces, flood plains and wetlands/filter beds. These sources are thought to contribute to the overall nitrogen budget to a large extend. However, the actual contribution cannot be quantified at the moment and should therefore be subject to future research on this topic.

12. There is the need to come to catchment scale N budget studies

In order to be able to quantify the nitrogen cascade from small or regional catchments, there is the need to come to nitrogen budget studies at this spatial scale. Such a study will give more insight in the source, sinks and pools of nitrogen at this scale. Results from a catchment scale N budget study can be used as an input for an independent verification approach e.g. in the context of the NitroEurope IP. As an example for performing such a catchment scale study, the 15N labelling approach was mentioned at a landscape level. It was recognized by the group that this might be a novel and challenging way to perform such a study. However, the feasibility of such an approach is not known yet and should be investigated.

13. There is the need for more insight in emission-concentration relations and their trends

Based on previous studies, it was recognized by the group that there is an ongoing need for more insight in the relation between emissions and the resulting concentrations and the changes in trends for these two items. This insight is needed for different reasons. Firstly, it can be used for model checking: from the information of both the emissions and concentration trends, an indication can be obtained of the validity of either the models used or the emissions. Secondly, a valid relation between emissions and concentrations will give confidence in the model estimates for the future situation and will, therefore, also adequately give information about the effects of different abatement strategies. A prerequisite for such a comparison between emissions and concentrations is the availability of adequate measurements, both in time and space (e.g. 3D-observations).

14. There is the need for studies on the consequences of upscaling and downscaling the nitrogen cycle

It was recognized by this working group that there is the need for studies on the consequences of upscaling and downscaling the nitrogen cycle. Through up- and/or downscaling there is the possibility of linking the analysis of the nitrogen cycle at different spatial scales, i.e. plot-scale, landscape-scale, regional catchments and national/regional scale. The up- and downscaling process progressively incorporates additional sources and/or sinks and transport scales. Part of this up- and downscaling process will be addressed during the NitroEurope IP activities in the 'Landscape' Component (C4).

15. **There is the need for incorporate recently identified mechanisms into regional models**

Different items were identified during the brainstorming session that need incorporation into the available regional models. These items were: effects of $NO-NO_2-O_3$ triad in canopy, effects of gas-particle interconversion in canopy, meteorology as a driving force on NH_3 and other N emissions. In general it was recognized that a lot of the detailed science on N-fluxes is yet to reach the application stage.

Annex 3.1 List of issues from the brains storm session

- European landuses; adequate measurement understanding
- fast flux measurement techniques (single height)
- upward emissions (biosphere atmosphere)
- canopy redeposition (within canopy cycling NO_x, NH_3 + chemistry)
- denitrification to N_2
- dispersion simulation
- advection and complex terrain (flux measurements)
- verification through whole catchment N-budgets: small & large scale catchments
- contribution of atmospheric deposition to land to riverine N inputs to sea
- emission-concentration links and trends
- magnitude of water surface emissions (sea & river) buffering mechanism (N_2O, N_2, NH_3) flood planes & estuaries
- climate effects sensitivity of transport & deposition: need for an integrated approach
- organic N: quantifying the role & magnitude
- wetland as a filter for pollution
- integrating aerosols into effect of N on GHG (global warning /cooling)
- vertical measurements (mountain top)
- scale of models & LRT
- coupling of NH_3 & meteorology
- cascade: measuring fluxes from original sources
  –following the cascade
  –landscape scale 15N-labelling