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FARMSIM: an integrated tool to model greenhouse gas emissions at the farm level

Jean-Louis Drouet, Sylvia Duret, Jean-Louis Fiorelli, Vincent Blanfort,
Mathieu Capitaine, Nicolas Capian, Benoit Gabrielle, Raphaël Martin,
Romain Lardy, Pierre Cellier, et al.

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Open Science Conference

Reactive Nitrogen and the European Greenhouse Gas Balance

February, 3rd and 4th, 2010
Landhaus, Solothurn, Switzerland



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of Economic Affairs FDEA
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Research Station ART



NitroEurope, Integrated Project (IP)
funded under the 6th Framework Programme
Priority 6.3 Global Change and Ecosystems



The Conference

This conference is organised by the NitroEurope Integrated Project¹ (IP), funded under the EC 6th Framework Programme. After four years of research have been completed we invite both the NitroEurope community and scientists outside the project to discuss the state of the art of research into the nitrogen cycle and its importance for the European greenhouse gas balance.

Several activities currently conduct and support research into the global Nitrogen cycle. Among these, the NitroEurope IP addresses the core question: What is the effect of reactive nitrogen (N_r) supply on net greenhouse gas budgets for Europe? In order to find answers to this question, the project strives to

- establish robust datasets of N fluxes and net greenhouse-gas exchange (NGE) in relation to C-N cycling of representative European ecosystems, as a basis to investigate interactions and assess long-term change,
- quantify the effects of past and present global changes (climate, atmospheric composition, land-use/land-management) on CN cycling and NGE,
- simulate the observed fluxes of N and NGE, their interactions and responses to global change/land-management decisions, through refinement of plot-scale models,
- quantify multiple N and C fluxes for contrasting European landscapes, including interactions between farm-scale management, atmospheric and water dispersion, and consideration of the implications for net fluxes and strategies,
- scale up N_r and NGE fluxes for terrestrial ecosystems to regional and European levels, considering spatial variability and allowing assessment of past, present and future changes,
- assess uncertainties in the European model results and use these together with independent measurement/inverse modelling approaches for verification of European N_2O and CH_4 inventories and refinement of IPCC approaches.

And while the project can build upon a strong partnership of 62 institutions, with more than 200 scientists from all over Europe and beyond, it is vital at this stage to reach out and engage with a wider scientific community to engage in discussions on the state of the art of N related research in Europe. By inviting keynote speakers from various fields outside the core objectives of NitroEurope and by welcoming contributions in the form of science papers and posters, the planned conference will support all of the objectives of the ESF-NinE programme. In particular, it will

- contribute to underpinning N research by bringing together scientists from various fields and disciplines working on related issues
- improve the linking between compartments, by including keynotes on aquatic and oceanic ecosystems,

¹ <http://www.nitroeuropa.eu>

- address issues of scale from plot to landscape to European and provide a platform to discuss and further the development of methodologies for up- and downscaling.
- the conference will be able to act as a catalyst for the further development of the European Nitrogen Assessment Report, hosting a side event bringing together key authors contributing to the report.

The conference is organised in 6 sessions:

1. Flux measurements of reactive nitrogen, pools and processes
2. Impacts of changes in external drivers (global change, N deposition, management, land use change etc.) on fluxes and exchange of N, C and GHG in terrestrial ecosystems
3. Plot scale modelling of processes controlling the biosphere-atmosphere exchange of trace gases to predict effects of changes in climate, land use and land management on gas exchange of C and N compounds
4. Upscaling from plot to regional scales – analysing interactions on different spatial scales
5. Assessment of nitrogen and green house gas fluxes in response to human influence at large regional scales
6. Verification and uncertainty assessment of N and GHG management across disciplines

In addition, the following keynote speakers have accepted the invitation to deliver talks on topics related to the conference theme:

- **Prof. Nina Buchmann** (ETH Zuerich, Switzerland): Effects of Plant Diversity on Carbon and Nitrogen Cycling in Grasslands
- **Prof. Janet Sprent** (emeritus professor at the University of Dundee, UK): Biological Nitrogen Fixation in Europe: does it matter?

The Venue

This year the NitroEurope General Assembly and Science Conference is taking place in Solothurn, Switzerland.

Solothurn, on the River Aare at the south foot of the Jura mountain range, is also known as St. Ursen City, Wengi City, the City of Ambassadors, Switzerland's most beautiful baroque city, and the city of culture. The conference venue – *the Landhaus* - used to be the landing site for wine shipments in earlier times. In 1955, it burned down to the foundation walls and was subsequently reconstructed. The town council hall is home to a large, three-coloured *sgraffito* by Hans

Jauslin along with episodes from the history of Solothurn. *Apollo and the Muses* by Maurice Barraud and *Three Women*, a bronze by Oscar Wiggli are found in the hall.



Local Organisation

The conference is co-organised by a team from the Swiss Federal Research Station for Agroecology and Agriculture. The NitroEurope IP is very grateful for the excellent ground support provided in particular by Albrecht Nefel, Pierluigi Calanca and Ivo Hutzli.

Financial Support

The conference organisers would like to express their gratitude to the Swiss Federal Offices for Agriculture (FOAG) and Environment (FOEN), the ESF Programme Nitrogen in Europe (NinE), COST-Action 729 and the International Nitrogen Initiative (INI) for supporting this event.

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Part A: Conference Papers

1. Flux measurements of reactive nitrogen, pools and processes

1.1. Organic nitrogen in European precipitation

Cape, N.J., Gonzalez, J

Contact: John Neil Cape (jnc@ceh.ac.uk)

Analysis of total dissolved nitrogen in precipitation samples from 21 sites operated by NEU participants across Europe has been combined with existing data on inorganic nitrogen (ammonium, nitrate) from the same samples to estimate the contribution of water-soluble organic nitrogen (WSON) to wet N deposition. The contribution to wet N deposition from WSON varies greatly across Europe, with lowest values in the mountains of central Europe (5% total N), and highest values in north-western Europe (50% total N). At some sites there were strong correlations between WSON and ammonium, at others there were correlations with nitrate, emphasising the complex nature of WSON and probable multiple sources.

Some of the limitations of the approach will be discussed in the light of new data from the UK, and conclusions drawn on the uncertainties in wet and dry organic N deposition as a contribution to N budgets.

1.2. Importance of inlet design in measurements of atmospheric ammonia

Ellis, R., Murphy, J.G., Whitehead, J.D., von Bobrutski, K., Jones, S., Blom, M., O'Brien, J.M.

Contact: Richard Ellis (rellis@chem.utoronto.ca)

A field intercomparison between eleven instruments for the measurement of atmospheric ammonia took place in Southern Scotland, UK in late summer 2008. Measurements were performed over grassland mainly used for sheep grazing to which fertilizer was applied in the second week to test the instruments' response times. Among the instruments present was a compact, fast response (1 Hz) Quantum Cascade Tunable Infrared Laser Differential Absorption Spectrometer (QC-TILDAS). The QC-TILDAS uses a novel sampling inlet, consisting of a short, heated, quartz tube with a hydrophobic coating to minimize the adsorption of ammonia to surfaces. The inlet contains a critical orifice that reduces the pressure, a virtual impactor for separation of particles, and additional ports for delivering NH₃ free background air and calibration gas standards. Comparison of the QC-TILDAS with its predecessor, a dual QC-TILDAS and with standard, traditional NH₃ measurement methods Ammonia Measurement by Annular Denuder with online Analysis (AMANDA) and its successor AiRRmonia showed very good correlation at higher NH₃ concentrations but considerably poorer correlation at concentrations lower than 10 ppb. This is mostly attributed to differences in inlet design, where

surface interactions are much more prominent at lower concentrations as suggested by supplementary laboratory experiments. In our laboratory studies, humidity was seen to worsen the NH_3 time response and considerable improvement was observed when using a heated sampling line. An additional field intercomparison between the QC-TILDAS and the chemiluminescence-based NH_3 analyzer performed at the rural site of Egbert, ON, showed the QC-TILDAS inlet design to have a faster time response to rapid changes in NH_3 concentration. The importance of careful inlet design and the suitability of the QC-TILDAS for eddy covariance ammonia fluxes will be discussed.

1.3. The exchange of oxidized nitrogen and ozone with a Dutch coniferous forest, Speulderbos

Fruma., A., Bleeker, A., Hensen, A., Erisman, J.W., van der Tol, C., Duijzer, J., Weststrate, H., van Pul, A., Stolk, A.

Contact: Arnoud Frumau (frumau@ecn.nl)

Within the framework of the NitroEurope project measurements of the major components of the N budgets as well as C budget have been taken up at the Douglas fir site Speulderbos. These measurements were performed previously during several projects in the nineties, with the forest left unaffected but growing swift ever since.

The current C and N budget is compiled from measurements for major components and a comparison with historic results is made. The total C budget of the forest is derived from eddy covariance measurements of the CO_2 exchange. The N budget of the forest is more complex, it includes gaseous exchange in many different forms (among others, NO , NO_2 , N_2O , NH_3), as well as input by rain and leaching of N-compounds with the soil water.

1.4. Mobile plume measurements of Ammonia from slurry application

Hensen, A., Kraai, A., van den Bulk, W.C.M., Bertolini, T., P. Di Tommasi, V., Magliulo, E.

Contact: Arien Hensen (hensen@ecn.nl)

Mobile plume measurements were performed downwind of two manured fields during the NEU-C4 campaign in Bjerringbro, Denmark (April 21-24 2009). Two Aerodyne Quantum cascade laser spectrometers mounted on mobile platforms were used to obtain NH_3 concentration patterns on roads 30 m downwind of the manured fields. The measurements took place on the first day after manure application. Typical concentration levels on the plume axis were in the order of 100-300 ppb. Metered releases of N_2O from the field were used as a tracer in order to assess the dispersion parameters to be used in a simple Gaussian transport model. In the model, plume concentration patterns, meteorological data and continuous measurements on a fixed location in the NH_3 plume (Amanda wet denuder system) are combined to obtain

emission estimates over time from the two fields. In the presentation the performance of the techniques used are discussed and a comparison is made between estimates based on the mobile and stationary measurements. The results in terms of NH_3 fluxes will be compared with “standard” emission factor estimates and with results obtained in similar experiments including LIDAR measurements in the Netherlands. Pro’s and cons of this type of measurements for N-emission evaluation will also be discussed.

1.5. Influence of grazing, cutting and fertilisation on the nitrogen, carbon and greenhouse gas budget from a Scottish grassland

Jones, S.K., Anderson-Dunn, M., Coyle, M., Campbell, C., Famulari, D., Di Marco, C., van Dijk, N., Drewer, J., McKenzie, R., Gonzales, A., Nemitz, E., Sutton, M., Skiba, U.

Contact: Stephanie Jones (skj@ceh.ac.uk)

Intensively managed grazed grasslands in temperate climates are globally important sources of the exchange of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Within the framework of the European projects Greengrass and NitroEurope C and N fluxes and pools were measured from a grazed, cut and fertilised grassland in the SE of Scotland from 2002-2008. The nitrogen budget is dominated by N import as fertiliser and loss as N_2O , N_2 and harvest (sheep). N_2O emissions are large and spatially and temporally highly variable. For example, the N fertiliser induced N_2O emission factor was 6.9% in 2007, but 3.8% in 2008. This grassland is a sink for CO_2 , however in global warming terms the sink strength is whipped out by the large N_2O emissions and CH_4 emissions from the ruminating sheep and the soil during the wetter months. A detailed synthesis of seasonal and interannual changes in pools and budgets are presented.

1.6. Nitrifier denitrification can be a source of N_2O from soil: a revised approach to the dual isotope labelling method

Kool, D.M., N., Wrage, N., Zechmeister-Boltenstern, S., Pfeffer, M., Brus, D., Oenema, O., Van Groenigen, J.W.

Contact: Dorien Kool (*Dorien.kool@wur.nl*)

Nitrous oxide (N_2O), a potent greenhouse gas, can be produced through a variety of biochemical pathways. Nitrifier denitrification, i.e. nitrite reduction by ammonia oxidizers, is one of them. This production pathway has been identified in monoculture studies, and it is increasingly suggested that it may contribute substantially to N_2O production in soil. As soils constitute the major global source of N_2O , understanding the significance of nitrifier denitrification is indispensable to effective mitigation of N_2O emissions. However, methodological drawbacks

thus far prohibited conclusive proof of its occurrence in soil.

We developed a new approach to identify the presence of nitrifier denitrification in soil. N₂O production was studied in soil incubations using oxygen (O) and nitrogen (N) isotope tracing, while accounting for O exchange between water and intermediate products of the N transformations. Twelve soils were studied which covered a diversity of soil and land-use types across Europe. We additionally aimed to link variation in N₂O production pathways to differences in the microbial community by examining microbial biomass C and N and phospholipid fatty acid (PLFA) patterns.

Our results showed that in at least five of the soils studied, nitrifier denitrification must have had a contribution to total N₂O production. Data revealed that in fact it may have been responsible for all NH₄⁺-derived N₂O in most soils. In contrast, N₂O as by-product of ammonia oxidation contributed marginally, if any, to total production. Surprisingly, none of the examined microbial parameters could adequately explain differences in N₂O production. Soil pH was the best predictor of the observed relative contributions of the pathways.

We conclude that herewith we finally demonstrate that nitrifier denitrification can indeed occur in soil, and may in fact be responsible for the majority of total nitrifier-induced N₂O. Our data further suggest that microbial community composition may not be a key driver in the relative significance of different N₂O production pathways, and that pH may be a principal factor determining nitrifier-induced N₂O production.

1.7. Inputs and outputs of nitrogen in a boreal Scots pine forest

Korhonen, J., Jalmari, F., Pihlatie, M., Pumpanen, J., Vesala, T.

Contact: Janne Korhonen (janne.fj.korhonen@helsinki.fi)

We studied nitrogen balance of a young boreal coniferous Scots pine (*Pinus sylvestris*) stand at SMEAR II -measurement station at Hyytiälä, Southern Finland (61° 51'N, 24° 17'E). The stand was established in 1962, and is managed by the current forestry recommendations. Bedrock under the acidic 0.05 -1.5 m deep soil is solid granite and is sealed with silt containing high portion of clay. Runoff and leaching of water and nutrients from two mini-catchments were measured from two weirs. We also measured *eg.* N deposition, throughfall and stemflow. Chambers were used to measure N₂O and NO_x exchange between the ecosystem and the atmosphere.

We found that soil is the greatest pool of N, approximately 2000 kg N ha⁻¹, of which approx. 99.9 % is bound to organic matter. Other important storages of N are wood, needles and fine roots, totally containing approx. 200 kg N ha⁻¹. In the woody tissue N is immobilized to living biomass from decades to hundreds of years, whereas the N in the needles and fine roots is immobilized from months to some years. In dead plant biomass N can be immobilized for millennia.

The atmospheric input of N is approx. 5 kg ha⁻¹ a⁻¹, of which up to 40% is measured as dissolved organic nitrogen (DON). Annual uptake of N by trees corresponds to approx. 1% of the total N stored in the ecosystem. Atmospheric N deposition is approx. 20% of the annual N uptake of trees. Most of the wet mineral N deposition does not reach the forest floor because of canopy interception, suggesting that canopy N uptake is substantial.

Less than $0.5 \text{ kg N ha}^{-1} \text{ a}^{-1}$ is lost from the system as runoff, which is dominated by DON. Approx. 0.3 kg N ha^{-1} is lost as N_2O . NO_x emissions from soils and shoots are negligible. We conclude that N accumulates to boreal forest ecosystem and that this accumulation occurs in time scales of centuries or millennia. Trees can get significant part of their N requirement by canopy uptake. Fraction of DON in inputs and outputs is considerable.

1.8. Volatile amines from agriculture

Kuhn, U., Sintermann, J., Spirig, C., Nefel, A.

Contact: Uwe Kuhn (uwe.kuhn@art.admin.ch)

Information on the occurrence of reduced nitrogenous compounds other than ammonia in the atmosphere is marginal. Volatile biogenic amines are ubiquitously formed by biodegradation of organic matter, and are assumed to be a significant component of the atmospheric N-cycle, but are not accounted for in recent assessments of the global N-cycle due to the scarceness of available data. There is increasing evidence for an important role of biogenic amines in the formation of new particulate matter, as well as for aerosol secondary growth. Agriculture is assumed to dominantly contribute to the budget of volatile biogenic amines. Here, we show results derived by means of impingers, a classical analytical sampling tool for compound qualification/quantification of NH_3 and amines in air, with subsequent (offline) analysis of the aqueous sample solution by Ion Chromatography. Measurements of volatile amines within livestock buildings revealed concentrations that were about 2 orders of magnitude lower than for NH_3 , confirming the few literature data available (e.g. Schade and Crutzen, *Journal of Atmospheric Chemistry* 22, 319-346, 1995). On the other hand, ambient air concentrations of amines after the application of manure over grassland were at least 4 orders of magnitude lower than of NH_3 . Further measurements in the headspace of manure storage pools, and from distilled manure, clearly indicated a depletion of amines relative to NH_3 during the processing of manure. We conclude that, in contrast to NH_3 , the direct release from livestock buildings dominates the agricultural budget of volatile biogenic amines, rather than the emission after manure spreading in the field. An approach as used by Schade and Crutzen (1995) transferring individual NH_3 /amine ratios found indoors of livestock buildings for the direct upscaling to the total agricultural amine emissions, based on existing NH_3 inventories, is not possible without consideration of the amendment of the NH_3 /amine ratios during manure storage.

Basic requirements for the application of the eddy correlation technique, representing the most direct flux method, are a high analytical sensitivity and a fast instrumental response time. In this way the technical adaptation and applicability of online Proton Transfer Reaction Mass Spectrometry (PTRMS) in a newly established mode (using O_2^+ instead of H_2O^+ as a primary reagent ion) for both volatile amines and ammonia will be discussed.

1.9. Summary of the N flux measurements and budget estimations over a grassland in Hungary (Bugac L3 site)

Machon, A., Horváth, L., Weidinger, T., Grosz, B., Pintér, K., Nagy, Z., Mohácsi, A., Pogány, A., Bozóki, Z.

Contact: Attila Machon (machon@freemail.hu)

According to the mandatory protocol for Level 3 sites comprehensive study has been carried out at Bugac semiarid grassland site in Hungary. To fulfil these requirements, carbon, nitrogen and water flux and balance measurements have been started in July 2006. Fluxes of N-compounds have been measured by routine methodology and techniques (e.g. static chamber for nitrous oxide, dynamic chamber for nitric oxide, inferential method for dry deposition, wet deposition measurements, etc.).

The presentation gives a short overview on the results of the micrometeorology and nitrogen flux measurements and N-balance estimation (based both on the measured N-exchange and ecological model simulation) for Bugac site for the last three years. Some case-study will be shown on the relationships among the unique landscape feature drivers (micrometeorology and soil parameters) and the common soil processes (denitrification) or N deposition.

Some preliminary results will also be presented on the continuous ammonia flux measurement by the diode laser photoacoustic detector, developed by Szeged University.

1.10. Review and parameterisation of bi-directional ammonia exchange between vegetation and the atmosphere

Massad, R.S., Nemitz, E., Sutton, M.

Contact: Raia Silvia Massad (rass@ceh.ac.uk)

Ammonia (NH_3) plays a role in aerosol formation and contributes to soil acidification and habitat loss through its contribution to excess nutrient loading. The impact of human activity on the nitrogen (N) cycle has made the parameterisation of NH_3 in air quality models an active area of research, for the sound underpinning of regulatory scenarios for human exposure to particulates, ecosystem nutrient loading and climate change. Current deposition schemes used in atmospheric chemical transport models do not generally account for bi-directional exchange. Bi-directional exchange schemes of NH_3 , so far only applied at the plot scale, can be included in transport models but need to be parameterised with the stomatal compensation point (χ_s) and cuticular resistance (R_w). We here review existing measurements of χ_s as well as R_w and compile a comprehensive data set as well as generalised parameterisations.

Concerning χ_s , we chose to divide land-use in two categories: managed and non-managed ecosystems. For managed ecosystems, the main source of N is fertilisation which is reflected as a peak in χ_s a few days following application but can also be reflected outside fertiliser application periods in the concentration of ammonium in the plants bulk tissue ($\text{NH}_4^+_{\text{bulk}}$). Studies show that $\text{NH}_4^+_{\text{bulk}}$ is also influenced by atmospheric N deposition (N_{dep}). The parameterisation we propose is based on a χ_s peak as a function of fertiliser application that gradually decreases to a background value. Background χ_s depends on N_{dep} derived from

NH_4^+ bulk. For non-managed ecosystems, the main source of NH_3 is N_{dep} , which is how we propose to parameterise χ_s . R_{cu} is commonly parameterised as a function of relative humidity (RH). We propose to parameterise R_{cu} as a function of RH, leaf area index, temperature, and $R_{\text{cu}(\text{min})}$. $R_{\text{cu}(\text{min})}$ depends on the ratio of total atmospheric acids to NH_3 concentrations according to four ecosystem types (arable, grassland, semi-natural and forest).

Although the approach presented is expected to be reasonably realistic, the parameterisation proposed may not apply to other ecosystems or geographical regions due to the lack of data. The next steps are to include this type of parameterisation in a large scale model and to validate its output with measurement networks and modelling exercises.

1.11. Quantification of process-based gross N transformation rates in soils based on ^{15}N tracing - theory and application

Müller, C., Rütting, T.

Contact: Christoph Müller (Christoph.Mueller@ucd.ie)

Knowledge of individual gross N transformation rates in soil is essential to understand internal N cycling processes and their contribution to N losses from terrestrial ecosystems. This paper revisits the theoretical background to quantify process-based gross N fluxes in soil. The ^{15}N pool dilution theory developed in the 1950s¹ is the basis for current ^{15}N tracing methodologies. One of the problems related to the traditional ^{15}N pool dilution technique is that it will not allow a separation of gross production rates into process-based pathways (e.g. mineralisation to NH_4^+ from different organic N pools in soil). Numerical techniques based on Bayesian data analysis are now available that can potentially overcome these shortfalls. Based on theoretical data sets and experimental results we demonstrate that new numerical analyses techniques are able to quantify process-based gross N transformation rates. This has provided us with new insights into the processes associated with N cycling in soil which will ultimately be useful to derive mitigation and sustainable land-management strategies.

1.12. State of art of micrometeorological NH_3 flux measurements

Nefel, A.

Contact: Albrecht Nefel (Albrecht.nefel@art.admin.ch)

NH_3 flux measurements are still challenging due to the “sticky” nature of the NH_3 molecule. Within the NitroEurope community large varieties of approaches have been developed and have been intercompared on several occasions. With the availability of fast NH_3 sensor based either on optical spectroscopy or mass spectroscopy direct Eddy Covariance approaches became possible.

The presentation aims to give an overview of the state of the art of the NH_3 flux measurements and to pinpoint to major difficulties.

1.13. Above and in-canopy profiles and fluxes of nitrogen compounds, particles and VOCs at Dutch forest – a first synthesis of the results from the 2009 NitroEurope campaign at Speulderbos.

Nemitz, E., Copeland, N., Coyle, M., Di Marco, C., Duyzer, J., Frumau, A., McGillen, M., Misztal, P., Percival, C., Phillips, G., Stolk, A., Westrate, H., Winchink-Kruit, R., Sutton, M.

Contact: Eiko Nemitz (en@ceh.ac.uk)

An integrated measurement campaign took place in June 2009 at the Dutch NitroEurope Level-3 site ‘Speulderbos’, as a collaboration between two UK (CEH, Univ. Manchester) and three Dutch institutes (ECN, RIVM and TNO). The objective was to use state-of-the-art instrumentation to quantify fluxes, emission and deposition rates of the different compounds and to study chemical interactions above and within the Douglas fir canopy, with emphasis of interactions of the $\text{NH}_3\text{-HNO}_3\text{-NH}_4\text{NO}_3$ and $\text{NO-NO}_2\text{-O}_3$ chemical systems. Measurements included:

- a) gradient flux measurements of NH_3 , HNO_3 , HONO, SO_2 , NH_4^+ , NO_3^- , SO_4^{2-} and Cl^- with wet chemistry analysers (GRAHAM, MARGA),
- b) eddy-covariance flux measurements of NH_3 with a novel setup based on a chemical ionisation mass spectrometer (CIMS),
- c) eddy-covariance flux measurements of sub-micron aerosol components (NO_3^- , SO_4^{2-} , NH_4^+ , organics) using an Aerodyne aerosol mass spectrometer,
- d) eddy-covariance measurements of size-segregated particle number fluxes (60-1000 nm) using a ultra high sensitivity aerosol spectrometer (UHSAS),
- e) virtual disjunct eddy-covariance measurements of volatile organic compounds (VOCs) using a proton transfer reaction mass spectrometer (PTR-MS),
- f) eddy-covariance flux measurements of ozone at three heights (one above and two within the forest canopy) to quantify vertical flux divergence, using fast dry-chemiluminescence analysers,
- g) chamber measurements of NO soil emissions and gradient flux measurements of NO, NO_2 and O_3 ,
- h) automated in-canopy gradient measurements of ozone, particle size-spectra, VOCs, CO_2 , and meteorological parameters.

This presentation will give an overview of the results from the various measurements and provide a first analysis of the linkage between the fluxes.

1.14. Low-cost DOAS instrument to measure ammonia concentrations and fluxes

Volten, H., Haaima, M., Kruit, W., Bergwerff, R.J.B., van der Hoff, G.R., Swart, D.P.J.

Contact: Helster Volten (helster.volten@rivm.nl)

Ammonia is brought into the atmosphere by industrial farming, by agricultural activities, and to a lesser extent by traffic and industry. These emissions have a major impact on nature areas and

biodiversity, in particular in the Netherlands but also in other parts of Europe. To study these problems, and to document levels and trends for environmental policymaking, there is a distinct need to accurately monitor the ammonia concentrations and ammonia deposition at different locations.

Measuring ammonia concentrations in air is complicated because of the sticky nature of ammonia. Instruments using sample lines often suffer from slow response times and hysteresis due to ammonia sticking to walls and tubing. In addition, ammonium aerosols trapped on filters may dissociate and cause interference.

A system to measure ammonia that is free of these drawbacks has been developed by the National Institute for Public Health and the Environment (RIVM). It is based on the *Differential Optical Absorption Spectroscopy* (DOAS) technique. The instrument measures ammonia truly in-situ, using a beam of white light over an open path with a length of 50 m; it does not sample the air through tubing like most other instruments. The DOAS has an extremely fast time response (up to 5 ms), a high accuracy (better than $0.2 \mu\text{g}/\text{m}^3$ for 5-minute averages), low maintenance demands, and a high up-time. It is insensitive to ammonium aerosols because it measures in-situ, and has no filters.

We will present results from ammonia concentration measurements in comparison with other ammonia sensors. We will also show deposition measurements by a gradient system employing two DOAS systems at different heights. Currently, a low cost version of the instrument is under development. Low cost, high up-time and low maintenance will make the low cost system highly suitable for use in monitoring networks and for deposition measurements. We hope to show the first results from this system as well

1.15. Flux measurements of ammonia at the NitroEurope Level-3 ‘Speulderbos’ site

Wichink Kruit, R., Stolk, A., van Zanten, M., van Pul, A.

Contact: Roy Wichink (roy.wichink.kruit@rivm.nl)

Long-term flux measurements of ammonia are carried out at the NitroEurope Level-3 coniferous forest site ‘Speulderbos’ in the Netherlands since September 2007.

Fluxes are obtained with the so-called aerodynamic gradient technique by combining concentration measurements at three heights (32, 36 and 44m) with eddy covariance turbulence measurements. The ammonia concentrations are measured with a GRAHAM wet annular denuder system. Compared to earlier ammonia measurement systems, the GRAHAM has higher accuracy and contains a quality control system. The ammonia flux measurements are used to monitor the long-term ammonia deposition on the forest and to study the exchange processes between the forest and the atmosphere.

In this paper, we will focus on the exchange processes between the forest and the atmosphere. We will present several model parameters that are important in modelling bi-directional surface-atmosphere exchange of ammonia, e.g. the derived stomatal compensation points for the ‘Speulderbos’ location and model parameters for the external leaf surface exchange. The results will be compared with earlier flux measurements at the ‘Speulderbos’ site in the 90’s.

1.16. Nitrogen and carbon balance of a wheat-barley-mustard-maize rotation over two-years near Paris (France)

Loubet, B., Laville, P., Lehuger, S., Ferrera, R., Genermont, S., Roche, R., Personne, E., Durand, B., Decuq, C., FLURA, D., Masson, S., Fanucci, O., Larmanou, E., Stella, P., Mascher, N., Cellier, P.G.

Contact: Benjamin Loubet (loubet@grignon.inra.fr)

Greenhouse gas (GHG) exchange by agricultural fields is a key question. Apart from carbon dioxide (CO₂), a well known GHG, nitrous oxide (N₂O) is an essential GHG emitted from nitrogen fertilised environments. Nitric oxides (NO_x) also contribute to GHG production as a precursor of ozone (O₃). These GHG emissions are greatly influenced by the nitrogen status and the water content of the soil-crop system. Hence, in order to better understand and hence predict the GHG emissions from agricultural soils, it is essential to measure GHG fluxes, and nitrogen fluxes and pools in the soil and plant system.

This paper synthesises two years of measurements of CO₂, CH₄, N₂O, NO_x and O₃ exchange from a wheat-barley-mustard-maize rotation in Grignon (France) using automatic chambers and Eddy-covariance techniques. Specific experiments allowed evaluation of these techniques against each other. The uncertainties of each flux are evaluated. These GHG flux measurements are then combined with estimations of the carbon emissions of the farming system and the indirect emissions to produce an estimation of a GHG balance of the field.

Additionally, the fluxes of all nitrogen species were estimated from field campaigns, inferential modelling and monthly averages concentrations at the site. These were combined with measurements of nitrogen pools in the soil and the plants to give an overview of the nitrogen cycle at the site. Efforts were made to evaluate and discuss the uncertainties in these fluxes and pools.

Finally the GHG and N fluxes are discussed in relation with the cropping system, the meteorological and soil conditions, the nitrogen supply and the local pollution.

1.17. Comparison of methane fluxes measured with eddy covariance and closed chambers from a Mediterranean rice paddy field.

Meijide, A., Manca, G., Seufert, G., Goded, I., Duerr, M., Magliulo, E., Di Tomasi, P., Cescatti, A.

Contact: Ana Meijide (ana.meijide-orive@jrc.ec.europa.eu)

Rice paddy fields are one of the greatest anthropogenic sources of methane (CH₄), the third most important greenhouse gas after water vapour and carbon dioxide. In agricultural fields, CH₄ is usually measured with the closed chamber technique, resulting in discontinuous series of measurements performed over a limited area, that generally do not provide sufficient information on the short-term variation of the fluxes. On the contrary, aerodynamic techniques

have been rarely applied for the measurement of CH₄ fluxes, as instruments with high precision, high sampling rates and short response time are required.

The recent availability of fast methane analyzer based on the off-axis integrated cavity output spectroscopy is now offering the possibility to measure turbulent fluxes of CH₄ by eddy covariance (EC). The EC technique provides integrated continuous measurements over a large area and may increase our understanding of the underlying processes and pattern of CH₄ emissions in this ecosystem.

For this purpose a Fast Methane Analyzer (Los Gatos Research Ltd.) was installed in an eddy-covariance field set-up in a Mediterranean rice paddy field in the Po Valley (Italy). Methane turbulent fluxes were measured during the rice growing season, and the results were compared with those obtained from manually operated closed chambers and analysed by gas chromatography. Both measurement techniques seemed to produce similar fluxes in the periods of high CH₄ production. The average CH₄ emission from the EC measurement was 90.9 nmol m⁻² s⁻¹. Methane emission was measured during most of the period when rice was flooded, but CH₄ consumption was also observed, especially at the beginning of the vegetation period.

1.18. Seasonal variation of ammonia fluxes between beech leaves and the atmosphere in relation to leaf nitrogen pools

Wang, L., Kofod Schjoerring, J.

Contact: Jan K. Schjoerring (jks@life.ku.dk)

Ammonia (NH₃) fluxes between beech leaves and the atmosphere were investigated in a 90-year-old forest canopy and related to leaf nitrogen pools and glutamine synthetase (GS) activities. Stomatal ammonia compensation point, χ_{NH_3} , were measured by both a twig cuvette and bioassay techniques involving measurements of pH and ammonium concentration in the leaf apoplastic solution. The χ_{NH_3} determined on the basis of the gas exchange measurements followed a seasonal variation with early-season peaks during leaf expansion (9.6 nmol NH₃ mol⁻¹ air) and late-season peaks during leaf senescence (7.3 nmol NH₃ mol⁻¹ air). In the mid-season, the χ_{NH_3} of mature green leaves was much lower (around 3 nmol NH₃ mol⁻¹ air), which was also lower than the NH₃ concentration in the ambient atmosphere. For comparison, χ_{NH_3} obtained by apoplastic bioassay were 7.0, 3.7 and 6.4 nmol NH₃ mol⁻¹ air in early, mid, and late season, thus agreeing reasonably well with χ_{NH_3} values derived from Ammonia the gas exchange measurements. Mean NH₃ emissions fluxes were 1.31 and 0.51 nmol m⁻² leaf surface area s⁻¹ during early and late season, respectively, while leaves were a sink for NH₃ during mid-season. The NH₃ emission from young and old leaves were paralleled by increasing apoplastic ammonium concentrations, while ammonium concentrations in the bulk tissue only increased during late senescence. It is suggested that apoplastic ammonium was associated with xylem-derived ammonium, while leaf tissue ammonium played an important role for NH₃ fluxes during senescence. In conclusion, the exchange of NH₃ between beech leaves and the atmosphere followed a seasonal variation with NH₃ emission peaks being related to nitrogen remobilization during early leaf establishment and late leaf senescence.

1.19. Environmental controls over soil–atmosphere exchange of N₂O, NO and CO₂ in a temperate Norway spruce forest

Wu, X., Brüggemann, N., Gasche, R., Shen, Z., Wolf, B., Butterbach-Bahl, K.

Contact: Nicolas Brüggemann (nicolas.brueggemann@kit.edu)

Trace gas exchange of N₂O, NO and CO₂ between soil and the atmosphere was measured with high temporal resolution for five years (2004–2008) at the Höglwald forest, Germany, using a fully automated measuring system. Based on these long-term continuous measurements, we calculated the annual budgets of soil–atmosphere trace gas exchange with high accuracy, and demonstrated substantial seasonal and interannual variations. The mean annual soil–atmosphere exchange of N₂O, NO and CO₂ at our site for the years 2004–2008 was 1.20 ± 0.09 kg N₂O-N ha⁻¹ yr⁻¹, 8.64 ± 0.19 kg NO-N ha⁻¹ yr⁻¹ and 7.15 ± 0.08 t CO₂-C ha⁻¹ yr⁻¹, respectively. Seasonal patterns of soil N₂O fluxes were characterized by event emissions, generally occurring during thawing after long-term freezing periods. In contrast to N₂O emissions, the seasonal patterns of NO and CO₂ soil–atmosphere exchange followed soil temperature changes, although a substantial increase in CO₂ emissions was also observed during the freeze/thaw periods. The fact that NO fluxes were higher than N₂O emissions during most of the entire observation period indicated that nitrification might have been the primary pathway of N-trace gas production in our study. The extremely high N₂O emissions and the substantial interannual variation of N₂O flux rates caused by the freeze/thaw effect demonstrate the need for long-term measurements with high temporal resolution in order to come up with more reliable estimates of soil-atmosphere trace fluxes.

1.20. Concentrations and exchange processes of the ammonia-nitric acid-ammonium nitrate triad above a spruce forest canopy

Wolff, V., Meixner, F.X., Trebs, I.

Contact: Veronika Wolff (veronika.wolff@art.admin.ch)

We have performed measurements of ammonia (NH₃), nitric acid (HNO₃), particulate ammonium (NH₄⁺) and particulate nitrate (NO₃⁻) at two levels above a spruce forest canopy in south east Germany (50°09'N, 11°52'E, 775m asl) within the framework of the EGER (ExchanGE processes in mountainous Regions) project. Gaseous NH₃, HNO₃, and particulate NH₄⁺, NO₃⁻, and also SO₄²⁻ were measured using the Gradient Analyzer for Aerosols and Gases (GRAEGOR) mounted on a tower. The GRAEGOR delivers half hourly resolved concentrations of gaseous and particulate water-soluble trace substances, measured simultaneously at two heights.

In this study, we investigate the limitations of the aerodynamic gradient method as a result of (a) precision requirements and (b) chemical divergence within the constant flux layer for the

respective reactive nitrogen compounds. Careful precision and error analysis proved suitability of the instrument for the determination of exchange fluxes from the measured concentration differences. Total ammonium and total nitrate fluxes were close to their aerodynamic maximum with daytime (10:00-16:00h) medians of $-126.75 \text{ ng m}^{-2} \text{ s}^{-1}$ and $-42.25 \text{ ng m}^{-2} \text{ s}^{-1}$ (in terms of nitrogen), respectively. To gain more information about the impact of phase changes within the $\text{NH}_3\text{-HNO}_3\text{-NH}_4\text{NO}_3$ triad on the observed gradients of individual compounds and subsequent flux determinations, we will apply a thermodynamic equilibrium model (ISORROPIA). Moreover, potential violations of the prerequisites for the application of the aerodynamic gradient method constituting of internal sinks or sources will be addressed using timescale analysis.

1.21. Field Measurements of Nitrogen Flows in a Rural Landscape (Overview of the NitroEurope Bjerringbro Field Experiment)

Theobald, M., Schelde, K., Cellier, P., Bertolini, T., Bienkowski, J., Bleeker, A., Boegh, E., Bordas, A., Bozoki, Z., Braban, C., Breuer, L., Butterbach-Bahl, K., Christen, B., Dalgaard, T., Ditomassi, P., Durand, B., Durand, P., Duret, S., Els, N., Exbrayat, J., Famulari, D., Flechard, C., Frede, H., Frumau, A., Hensen, A., Janku, K., Kraai, A., Magliulo, E., Pogany, A., Riddick, S., Sanz - Cobena, A., Schlentner, G., Sutton, M., Thomsen, A., van den Bulk, P., Weidinger, T., Willibald, G., Wohlfart, T.

Contact: Mark Theobald (mrtheo@ceh.ac.uk)

The flows and transformations of reactive nitrogen (Nr) within a rural landscape are complex. To understand these processes it is necessary to study real landscape systems making use of field measurements and model simulations. To improve this understanding, simultaneous measurements of the flows of Nr through the different components of a rural landscape (vegetation, soil, atmosphere, streams) were made during a two-week field campaign in April 2009. The study landscape chosen was Bjerringbro in the Mid-Jutland region of Denmark. This choice was based on the agricultural activities of the area (mostly arable crops and pigs), farmer cooperation, landscape characteristics and local expertise. Twenty-five scientists from 11 research groups took part in the field campaign, which made use of a range of measurement techniques from low to high-technology. These included measurements of surface-atmosphere exchange of greenhouse gases (using absorption spectroscopy eddy covariance and manual/automatic chambers), atmospheric concentrations of ammonia (using passive samplers and continuous analysers) and stream chemistry (in-situ and laboratory analysis). The measurements were focussed on an area of approximately $3 \times 2 \text{ km}$, containing three farms and two branches of a stream network. During the experimental period, two of the arable fields in the landscape were fertilised with pig slurry, which represented the principal movement of Nr within the landscape. For this reason most of the measurements were made around these two fields, supplemented by additional measurements throughout the landscape (passive samplers, manual chambers and mobile gas analysers). The measurements revealed the large spatial and temporal variability of Nr within the landscape as well as the large transfer of Nr from the field-applied slurry to the atmosphere (in the form of ammonia and nitrous oxide emissions) and to the soil nitrogen pool. Although there was no direct flow of Nr from the fields where slurry was applied to the stream network (due to dry conditions), an imprint in the tile drain system was observed. In addition, a general difference in stream chemistry between the two stream branches was also found.

1.22. European scale modelling of groundwater denitrification and associated N₂O production

Keuskamp, J., van Drecht, G., Bouwman, L.

Contact: Lex Bowman (Lex.bouwman@pbl.nl)

We present a model for denitrification and N₂O production in groundwater systems. Similar to Van Drecht et al. (2003) we distinguish two groundwater subsystems. The shallow system (upper 5 meters of the saturated zone modelled on a 1 by 1 km resolution) is characterised by short residence times before water enters local surface water or deeper groundwater. The fraction overland- or interflow is reflected by a groundwater recharge factor depending on slope, effective porosity and groundwater level. The deep system has longer residence times and processes are described at the catchment scale. The deep system is recharged by water flowing from the shallow system and drains to larger rivers as baseflow. Areas having deep groundwater are identified using lithology. Alluvial and non- or semiconsolidated sediments have substantial deep groundwater flow. In other formations groundwater flow is hampered and long distance groundwater flow is impossible, so the shallow aquifer system drains to surface water. N₂O is an intermediate product of denitrification. We combined the estimation of reaction progress with N₂O dynamics based on the Hole-in-the-pipe model of (Firestone and Davidson, 1989). Reaction progress during transport is defined as $1 - \frac{[\text{NO}_3] + [\text{N}_2\text{O}]}{[\text{NO}_{3\text{in}}] + [\text{N}_2\text{O}_{\text{in}}]}$. This approach predicts no N₂O formation if denitrification takes place, while N₂O is completely reduced if NO₃ concentrations decline. We apply the model to current management conditions. We compare modelled denitrification progress and N₂O in groundwater for a number of different situations covering a wide range of groundwater systems in Germany.

Firestone, M. K. & Davidson, E. A. (1989) Microbiological basis of NO and N₂O production and consumption in soil, in Andreae, M. O. & Schimel, D. S. (eds) *Exchange of trace gases between terrestrial ecosystems and the atmosphere*. Chichester, Wiley and Sons, 7-21.

Van Drecht, G., Bouwman, A. F., Knoop, J. M., Beusen, A. H. W. & Meinardi, C. R. (2003) Global modeling of the fate of nitrogen from point and nonpoint sources in soils, groundwater and surface water. *Global Biogeochemical Cycles*, 17, 1115, doi:10.129/2003GB002060.

2. Impacts of changes in external drivers (global change, N deposition, management, land use change etc.) on fluxes and exchange of N, C and GHG in terrestrial ecosystems

2.1. Constraining the nitrogen budget of the NitroEurope Level 3 grassland sites

Ammann, C.

Contact: Christof Ammann (christof.ammann@art.admin.ch)

Greenhouse gas budgets as well as the productivity of grassland systems are closely related to the carbon and nitrogen (N) cycles. The main (Level-3) field sites in the NitroEurope project are supposed to measure 95% of the N fluxes to and from the ecosystem at the field scale. We analyse and compare the components of the nitrogen budget of the three managed grassland Level-3 sites Oensingen, Easter Bush, and Bugac. Depending on the intensity of the management, the nitrogen import by fertiliser and export by harvest or grazing represent major contributions to the N budget. Besides, wet deposition by rain and leaching of N-compounds with the soil water may constitute important pathways. Finally, gaseous exchange (dry deposition and emission) of nitrogen occurs in many different forms (NO, NO₂, HNO₃, N₂O, NH₃, N₂) needing different analytical techniques. For closing of the ecosystem N budget, also the accumulation (sequestration) within or the loss from the ecosystem (mainly soil organic matter) has to be considered.

The contribution of the different exchange pathways and their uncertainty are quantified for the three sites. Major uncertainties or gaps of the nitrogen budget are identified.

2.2. Effect of emission reduction measures on the bulk deposition of eutrophying and acidifying species in Southeast Lower Saxony, Brandenburg, Saxony and Hesse – results of long-term measurements

Dämmgen, U., Matschullat, J., Zimmermann, F., StrogiesM., Grünhage, L.

Contact: Ulrich Daemmgen (ulrich.daemmgen@daemmgen.de)

Emission reduction policy in Germany became effective with the Ordinance on Large Combustion Plants (“Großfeuerungsanlagenverordnung”) which came into force in 1983 (set into force in eastern Germany after reunification as well). It showed major impact on acidifying compounds (SO₂, NO_x) and particulate matter. In addition – to set standards – the Technical Instruction on Air Quality Control (“TA Luft”, 1986) and the Ordinance on Small and Medium Sized Combustion Facilities (“Verordnung über kleine und mittlere Feuerungsanlagen”) came into force for smaller facilities in 1988. These ordinances were amended in subsequent years to

achieve further reductions. However, the first major step aiming at a reduction of NH_3 emissions was the European Directive on National Emission Ceilings (2001) coming into force in 2004.

Long term bulk deposition measurements in Southeast Lower Saxony, Brandenburg, Saxony and Hesse indicate that these measures were effective to reduce the bulk deposition of SO_4 . Halving of NO_x emissions between 1990 and 2005 resulted in halving of the bulk deposition of NO_3 in the same period. Apart from the effect of the reduction of animal numbers in the former GDR, as a consequence of the German unification, no emission reduction was achieved for NH_3 . Nonetheless bulk deposition of NH_4 decreased considerably. This can be attributed to the decreasing amount of atmospheric acids, in particular of SO_2 and its reaction products. Reduced bulk deposition rates should have been compensated for by increased dry deposition rates. No time series exist for this deposition pathway. However, measurements of NH_3 background concentrations indicate a steady increase in NH_3 concentrations and the correctness of the assumptions about the dry deposition of NH_3 . Measurements of NH_4 concentrations in fine particles ($\text{PM}_{2.5}$) show that the considerable fraction of NH_4HSO_4 in NH_4 salts, observed in the early 1990s, has been replaced by neutral NH_4 salts during the past decade.

2.3. Comparison of greenhouse gas fluxes from soil under bioenergy and conventional crops

Drewer, J., Lloyd, C., Finch, J., Bottoms, E., McNamara, N., Skiba, U.

Contact: Julia Drewer (juew@ceh.ac.uk)

Bioenergy is a key component in the UK Government's plans for tackling energy security and climate change; the latter because it is perceived to be 'carbon neutral', i.e. the carbon emitted in using energy is balanced by the carbon absorbed in the growing feedstock. The target is that by 2020, 1 million ha (17% of the total UK arable land) will be available for energy feedstocks, including 350,000 ha for energy crops. However, the effects of miscanthus and short rotation willow on the soil fluxes of N_2O , CO_2 and CH_4 during their growth are not well known. These crops require different management, e.g., they are not limed, require lower N inputs for production, and tend to exhibit greater water-use efficiency than conventional crops. This potentially has a significant effect on soil biogeochemistry and microbial populations and therefore likely also on net GHG emissions from soil.

This study was carried out in Lincolnshire, NE England on adjacent fields of willow (*salix*), miscanthus, wheat (*triticum*) and oilseed rape (*Brassica napus*) on a heavy clay soil. N_2O and CH_4 flux measurements were made monthly using static chambers, CO_2 fluxes were measured continuously by eddy covariance.

Results to date show higher N_2O emissions from soils under conventional crops than bioenergy crops. Average fluxes for the period Jun 2008 to Aug 2009 were 9 and 34 $\mu\text{g m}^{-2} \text{h}^{-1}$ $\text{N}_2\text{O-N}$ from wheat and oilseed rape and 7 and 1 $\mu\text{g m}^{-2} \text{h}^{-1}$ $\text{N}_2\text{O-N}$ from miscanthus and willow, respectively. No clear trend in CH_4 fluxes could yet be identified. These observations are important regarding future land-use and management policies. Controlling factors will be discussed as well as differences between crops and seasonal variations. Additionally controls of

N₂O/CH₄ emissions will be presented to assess potential change in future GHG emissions. Initial results show that N₂O emissions from bioenergy crops may be lower than from conventional crops. This is probably due to the higher use of fertiliser in conventional cropping and annual ploughing. Due to seasonal and interannual variations in the soil and climatic conditions and physiological changes during the circa 20 year live time of the bioenergy crops it is important to continue these greenhouse gas measurements long-term before the on field carbon footprint of the bioenergy crop can be properly evaluated.

2.4. Greenhouse gas emissions and microbial community characterization by phospholipid analysis in a paddy rice soil (Lomellina, Lombardy)

Ferrè, C., Comolli, R., Andersson, M., Zechmeister-Boltenstern, S., Seufert, S.

Contact: Chiara Ferrè (c.ferre@campus.unimib.it)

A rice paddy experimental site, located in the Po plain (Castellaro de' Giorgi, Lombardy) was selected for gas exchange measurements (N₂O, CH₄ and CO₂) between soil and atmosphere. At eight sampling dates - representative for different soil conditions and for different crop stages - microbial community structure was characterized by phospholipid fatty acid analysis (PLFA); microbiological data were consequently correlated with gas flux rates.

The soils are Gleysols, the soil texture is mainly loam and clay-loam; the surface nitrogen content lies between 0.16 and 0.38%, while surface organic carbon content ranges between 1.38 and 3.52 %.

Principal component analyses revealed clear differences between sampling periods; soil conditions and crop stages significantly affected microbial community biomass and structure as well as gas emissions from the investigated rice field.

The following changes in the microbial community composition at different sampling times were observed: The ratio between Gram-positive and Gram-negative bacteria was higher in flooded than in un-flooded soils. The saturated fatty acids such as, a15:0, i15:0, i14:0 and the methyl-branched fatty acids 10Me17:0 and 10Me16:0, typically present in Gram-positive bacteria seemed sensitive indicators for flooded and waterlogged conditions which were favorable to the production and emission of methane as well as to the complete denitrification to N₂. On the contrary, Gram-negative bacteria were most important for characterization of aerobic and drier conditions and for the decomposition of fresh straw material. In terms of microbial processes the 16:1(9), cy17:0 and 18:1(11) fatty acids seemed to be correlated with N₂ production.

The vertical distribution of PLFAs was also investigated; the uniformity in carbon, pH, texture, nitrogen, nitrate and water contents of studied thickness resulted in a vertical homogeneity of microbial biomass and of community composition. Only temporary variations of surface nutrient availability, due to agricultural practices, led to a distinction between microbial populations of the two investigated layers (0-15 and 15-30 cm).

2.5. Nitrous oxide emissions from winter wheat cropland at landscape scale in France

GU, J., Nicoullaud, B., Rochette, P., Pennock, D.J., Cellier, P., Richard, G.

Contact: Jiangxin GU (Jiangxin.Gu@orleans.inra.fr)

Variables such as soil type, soil moisture or temperature, are strong controllers of nitrous oxide (N₂O) emission from agricultural soils. However, their regulatory effects vary spatially and temporally in rural landscapes. An improved understanding of what controls N₂O emissions at the landscape scale is thus helpful in scaling up these emissions to regional/national scales. In this study N₂O emissions were measured along three slopes (1.6 - 2.1%) in winter wheat cropland in a spring season within a 10 km² area in the centre of France by non steady-state chamber technique. The objectives were to characterize the N₂O emissions at different landform positions (shoulder and foot-slope positions) and to identify the controlling factors of their spatial variations. The results showed that landform positions had significant, but not consistent, effects upon N₂O fluxes. The N₂O fluxes were greater in the foot-slope than those in the shoulder positions in a north facing slope, and showed the contrary condition in the other two south facing slopes. The N₂O emission rates ranged between 0.002 - 0.111 mg N m⁻² h⁻¹, and increased exponentially with soil mineral nitrogen concentrations ($r^2 = 0.57$, $p < 0.001$). When the Water Filled Pore Space (WFPS) values were $< 60\%$ and $> 60\%$, the soil mineral nitrogen could explain 28% ($p = 0.05$) and 89% ($p < 0.001$) of variations in N₂O fluxes, respectively. The differences of Gravimetric Soil Water Content (GSWC) correlated linearly to the differences of N₂O fluxes between shoulder and foot-slope positions at the landscape scale ($r^2 = 0.45$, $p < 0.001$). It seems that slope facing and soil silt content regulated the soil moisture, though their regulatory effects need to be further confirmed. With the same nitrogen input rate of 170 kg N ha⁻¹, the cumulative N₂O fluxes ranged between 266 - 761 g N ha⁻¹. The order of the mean cumulative fluxes in the three slopes indicated that a precise division of fertilization might be useful for reducing the fertilizer induced N₂O emissions.

2.6. Long-term (11 years) of free-air CO₂ enrichment significantly increased N₂O emissions from a permanent German grassland

Kammann, C., Müller, C.

Contact: Claudia Kammann (Claudia.Kammann@uni-giessen.de)

Atmospheric CO₂ concentrations have increased by 35% since pre-industrial times to actually 384 ppm CO₂ and continue to increase at accelerating rates. Although the fear to cross tipping points (driven by forward feedbacks) in the earth' climate system increases, possible feedbacks such as the effect of elevated CO₂ atmospheres via plants on soil N transformation processes

and N₂O emissions have scarcely been investigated. In a long-term German FACE study in permanent grassland running since May 1998, the chosen target CO₂-enrichment concentration closely resembles the "critical" atmospheric CO₂ level of 450 ppm which should not be exceeded to avoid dangerous climate change.

We measured N₂O fluxes over more than 11 years 2-3 times weekly with 3 maxi-chambers per plot in the Giessen-FACE study (n=3 ambient- or elevated-CO₂ plots, respectively). No significant differences were present in the N₂O fluxes during the vegetative growth period 1997 prior to the start of the FACE experiment. With the onset of CO₂ enrichment, N₂O emissions increased strongly but non-significantly. Over several years of the study, the stimulation of N₂O emissions became more and more homogeneous, i.e. the CO₂ effect grew significant over time (Kammann et al., 2008), a pattern that continues up to date. Averaged over >11 years of CO₂ enrichment, the mean N₂O flux rates were 13.78 and 7.77 μg N₂O-N m⁻² h⁻¹ under elevated and ambient CO₂, respectively (P = 0,025, t-test). Integrated on a daily basis the additional N₂O released during 11 years under elevated CO₂ was equivalent to 5.32 tons of CO₂, an amount that must be sequestered under elevated CO₂ in form of soil carbon to balance the *increase* in N₂O emissions. However, this did not occur.

At the NUE conference we will show patterns of the seasonal responses of N₂O emissions to elevated CO₂ (e.g. freeze-thaw periods) and analyse possible causes and mechanisms behind these shifts in N₂O emissions. The talk also aims to present the fairly large N₂O flux data set and site (e.g. 979 measurements, half-hourly climatic data) to a broader scientific community to serve other groups for e.g. modelling-validating purposes.

2.7. Annual emissions of N₂O from eight organic soils under contrasting management

Petersen, S., Elsgaard, L., Chr. Hoffmann, C., Schäfer, C., Blicher-Mathiesen, G.

Contact: Soren Petersen (soren.o.petersen@agrasci.dk)

Between September 2008 and September 2009 a monitoring study was conducted to describe the greenhouse gas balance of eight organic soils under permanent grass (three sites), grass in rotation (two sites), or other crops in rotation (three sites). In this presentation the main focus will be on N₂O emission patterns and ecosystem respiration. The field sites were located in three clusters representing important regional variation in Denmark with respect to soil conditions and climate. Measurement campaigns were conducted every three weeks using two-part static chambers. Emission measurements at each site have been accompanied by continuous recordings of air temperature, soil temperature at four depths, soil moisture at two depths and ground water level during the 13-month period. In addition, groundwater samples were taken during sampling for analysis of pH, conductivity and mineral N. Also, new methods for monitoring soil N₂O concentrations above and below the groundwater level have been investigated. The soil profile at each site was characterized to 1 m depth by the end of the monitoring program. A multiple linear regression model is used to describe empirical relationships between categorical and continuous variables and N₂O emissions. Significant relationships will be used for estimation of annual fluxes, and for upscaling.

2.8. Influence of crop rotations on N₂O emission in agricultural field system in Southern Italy

Ranucci, s., Bertolini, T., Ottaiano, L., Di tommasi, P., Oliva, M., Vitale, L., Magliulo, V., Fierro, A.

Contact: Silvia Ranucci (silviaranucci@gmail.com)

Elevated emissions of greenhouse gases from agriculture are associated with intensive crop management. Cropping system, management and environmental variables play a key role on N₂O production. This work aims to quantify the influence of crop management on N₂O fluxes and emission factors as a function of different soil textures.

To describe emission patterns in a course of several growth seasons, N₂O emissions were monitored in a crop rotation including maize, fennel and ryegrass-clover mixture, from May 2007 to September 2009. The work was carried out at Borgo Cioffi (Eboli, Sa), a permanent study site part of NitroEurope network.

N₂O emission peaks followed fertilization events and were mainly associated with high temperature and elevated soil water content due to rainfall or irrigation. Differences due to the standard and normalized dataset will be discussed.

2.9. Nitrogen cycling in afforested organic soils related to N₂O

Rütting, T., Thomsen, F., Boeckx, P., Klemmedtsson, L.

Contact: Tobias Rütting (tobias.rutting@dpes.gu.se)

Afforested drained organic soils are an important source for atmospheric N₂O, accounting for 15% of the total N₂O emission from Swedish forests^[1]. The N₂O emissions from these forests are closely related to the soil C/N ratio, with significant fluxes at C/N < 20^[2], and are influenced by the soil pH^[3]. Here we present results from studies at two NitroEurope IP experimental forest sites on drained peat soils in south-western Sweden, which are afforested with either Norway spruce (Skogaryd) or silver birch (Falköping).

At Skogaryd we measured the soil N₂O emission year-round with manual flux chambers. We are particularly interested in the role of the rhizosphere (root and mycorrhiza) on N₂O fluxes, which is investigated by a soil trenching approach. The understanding of the underlying soil processes for high N₂O fluxes is still limited and needs further investigations. Therefore, we performed an *in situ* ¹⁵N labeling experiment, using the virtual soil core method, to investigate gross N transformations. This technique allows uniformly applying the ¹⁵N tracers, while the soil remains undisturbed in the ecosystem.

An additional ¹⁵N experiment was conducted in Falköping, which has a natural pH gradient of 3.5-7.0. The aim of this experiment was to investigate the effect of soil pH on gross N dynamics. Therefore, gross N transformations were quantified for three different pH levels

(high = 6.1; medium = 4.1; low = 3.4).

We will discuss how ^{15}N labeling experiments help to explain the high N_2O emissions from afforested drained organic soils and how the soil N cycle is influenced by environmental factors (pH and C/N ratio).

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2.10. Nitrogen cycling and greenhouse gas exchanges in a sub-alpine forest subjected to experimentally increased N deposition for 15 years

Schleppi, P., Krause, K.

Contact: Patrick Schleppi (schleppi@wsl.ch)

Increased deposition rates were simulated in a small catchment within a spruce (*Picea abies*) forest at Alptal (central Switzerland, 1200 m a.s.l.). This treatment was applied by sprinkling rain water enriched with NH_4NO_3 (+20-25 kg/ha/a N) and compared with a control catchment receiving only rain water (12 kg/ha/a bulk N deposition) and where NO_3^- -N leaching is approximately 3 kg/ha/a.

During rain events, NO_3^- concentration in runoff water was correlated with the water discharge, both showing simultaneous peaks. Labelling with ^{15}N showed that these peaks partly arise from NO_3^- deposited during the rain event itself. Preferential and lateral water flow promote very fast leaching in the gleyic soils of the site. NO_3^- losses thus doubled after only few weeks of the N addition experiment. These losses increased over time to reach roughly one third of the added N after 10-15 years. In the soil, both NO_3^- , NH_4^+ ions are rapidly immobilised, less than 2% still being extractable after one week. During the same time, an equilibrium between NH_4^+ and NO_3^- is reached, independently of which ion was deposited (or added as ^{15}N tracer). The ^{15}N signal disappears from NO_3^- leaching within weeks as labelling stops. At the same time, the hydrolysability of recently added N in the soil is comparable to that of native N. N immobilised in the soil thus appears to be stable in the long term and still accounts for most of the N retained in the ecosystem and induces a decrease in the C:N ratio of the top soil by one unit every 2 to 3 years.

The N saturation induced by the experimentally increased deposition also affects the greenhouse fluxes of the forest. Three years of measurements with static chambers showed increased emissions of nitrous oxide. A tendency to reduce soil respiration was also observed.

2.11. Potential greenhouse gas emissions from fifty European soils under different land use

Kitzler, B., Schauffler, G., Huang, Y., Wagner, D., Zechmeister –Bolstern, S.

Contact: Sophie Zechmeister (sophie.zechmeister@bfw.gv.at)

In order to estimate potential greenhouse gas emission rates from soils under different land use and climate and to particularly assess the influence of soil temperature and soil moisture we measured fluxes of nitrous oxide (N₂O), nitric oxide (NO), carbon dioxide (CO₂), and methane (CH₄) from intact soil cores obtained from fifty European Level 1 sites under controlled laboratory conditions. The soils covered the different climates of Europe and included four different land use types: croplands, forests, grasslands and wetlands. In a two-factorial experimental design, the soil cores were incubated under four different temperatures (5 – 20 °C) and water contents (20 - 80% WFPS). In this presentation the work of four years is summarized. Different land use types strongly affected greenhouse gas emission. Nitrous oxide and CO₂ emissions were highest in grassland soils, while NO emissions were highest in forest soils. In grasslands high soil microbial activity stimulated by high C and N contents, dense root systems and high C input from aboveground decaying biomass were the most likely cause for high N₂O and CO₂ emissions. High NO emissions from forest soils were mainly attributed to low pH and high soil porosity.

We found a strong non-linear increase of N₂O, NO and CO₂ emissions with increasing temperature. Nitrous oxide emissions were positively correlated with soil moisture, while NO emission and CH₄ oxidation rates were negatively correlated with soil moisture. Maximum CO₂ emissions occurred at intermediate soil moisture. Multiple regression equations based on soil moisture-temperature relationships explained up to 84% of the measured variations in greenhouse gas emissions. These relationships are useful to test and refine process-oriented models to improve the simulation of trace gas emissions under future climate conditions.

2.12. Assessing the mitigation potentials of NO₃ leaching of alternative crop management systems at European scale

Schmid, E., Balkovic, J., Schwab, D.E., Schönhart, M.

Contact: Erwin Schmidt (erwin.schmid@boku.ac.at)

Nitrogen is one of the major nutrients in agricultural crop production. Beside its agronomic importance, high application rates can negatively affect agro-ecosystems such as reducing biodiversity on agricultural sites (Kleijn et al., 2009) or may lead to increased greenhouse gas emissions such as N₂O. Furthermore, nitrates are highly soluble and excess easily leaches into surface and groundwater aquifers, where it can lead to contamination of drinking water or eutrophication of aquatic ecosystems. The EU directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources sets a nitrate concentration threshold of 50 mg/l in groundwater, which is still not met in many European

regions (EEA, 2009).

We have developed a data-modelling tool that is capable in analysing bio-physical impacts of alternative crop management practices on nitrate emissions below subsoil at EU scale. Such modelling tool is also requisite to assess efficient mitigation policies. The data-modelling tool consists of several geo-referenced and statistical datasets commonly available at European scale (MARS, CORINE, ESDB v.2, OC Top v.1.2, EUROSTAT, GTOPO, etc.) as well as the bio-physical process model EPIC (Environmental Policy Integrated Climate; Williams, 1995; Izaurralde et al., 2006). The data has been processed to delineate Homogenous Response Units (HRU) representing a unique combination of soil, weather, topography and land cover, which are necessary for plot-scale modelling at large scales. Among alternative crop management systems are crop rotations, fertilizer and irrigation regimes, tillage systems, and straw management systems. Likely crop rotations have been identified with CropRota (Schönhart et al., 2009) for each NUTS2 region using NewCronos historical land use data. Nitrogen fertilizer rates are calculated based on nutrient uptakes and historical crop yields on NUTS2 level (NewCronos). Sites with irrigation are located with maps of CORINE and PELCOM. Alternative tillage (i.e. conventional, reduced, and minimum) and straw management (w/ and w/o straw removal) systems are defined for each of the 20 crops.

The bio-physical potentials of mitigating NO₃ leaching through alternative crop management systems are assessed through a comparative dynamic analysis approach. Each crop management system is simulated with EPIC for a 10- and a 20-year period to assess the crop management effects in the medium- and long-run. The effects on crop yields as well as nitrogen loads in percolation water below subsoil are analysed in spatial, temporal and crop management contexts.

2.13. Effects of temperature, drought and elevated CO₂ on N₂O fluxes and N cycling in an upland grassland ecosystem: interactions with plant and microbial community structure

Cantarel, A.A.M., Bloor, J.M.G., Poly, F., Soussana, J.F.

Contact: Amelie Cantarel (cantarel@clermont.inra.fr)

Climate change is predicted to have significant impacts on soil processes and plant community structure, with cascading effects on ecosystem function and the cycling of trace greenhouse gases. Effects of climate change on nitrous oxide (N₂O) emissions are of particular interest given the high global warming potential of N₂O and its contribution to stratospheric ozone destruction. We used a grassland ecosystem manipulation experiment to investigate N₂O fluxes in response to increases in temperature, summer drought and elevated CO₂ over a two year study period. Our objectives were to i) quantify the amplitude of changes in N₂O fluxes to components of climate change on a seasonal and annual basis, ii) determine the relative contribution of direct and indirect effects (via plant community structure) of climate change on N₂O fluxes and iii) assess the relationship between N₂O fluxes and the activity, size and composition of the microbial pool under different climatic conditions. Climate treatments were applied to *in situ* replicated grassland monoliths in an additive experimental design, with continuous recording of air temperature and soil moisture content. N₂O fluxes were measured at

two-weekly intervals from January 2007-March 2009 using closed static chambers and a photoacoustic gas analyser. Biomass production, plant traits and community composition were determined in spring and autumn each year. Soil sampling and microbial analysis was carried out for three flux measurement campaigns in 2009. Our results show that N₂O emissions varied significantly between seasons: emissions in spring were significantly greater compared with winter. On an annual basis, climate change treatments had no significant effect on either the frequency or magnitude of N₂O emissions, but there was a trend towards increased net fluxes under elevated temperature. In addition, we found that temperature was a greater driver than soil moisture for microbial activity and variation in N₂O emissions. However, net N₂O fluxes were more strongly influenced by changes in aboveground production rather than by direct climate effects.

2.14. Relations between the structure of the denitrifying bacterial community and the current N₂ and N₂O flux rates at a long term fen grassland N fertilization experiment

Augustin, J., Behrendt, U., Ulrich, A.

Contact: Juergen Augustin (jaug@zalf.de)

Drained fen peatlands of north-east Europe constitute an important source for nitrous oxide (N₂O) emissions into the atmosphere. However, not only the knowledge about the effect of soil chemical and physical properties, climate, vegetation, and management on the actual N₂O and N₂ fluxes is very incomplete at fen soils. There are also no information about the role of structure and activity of denitrifying microbial communities in this context either.

Therefore relatively undisturbed soil columns (250 cm³) from a long-term N-fertilization experiment on a fen grassland (over a period of 45 years) were used for measurement of the current N₂ and N₂O fluxes (helium atmosphere incubation technique) followed by processing the soil sample for microbiological analysis immediately to investigate the influence of N-fertilization on these parameters.

Results showed a strong influence of N-fertilization and soil moisture on the emission of N₂ and N₂O. Shifts in the total microbial community were estimated by phospholipid fatty acid analysis. Results showed that seasonal effects interfered the influence of N-fertilization on shifts of the total microbial community composition. To characterise the denitrifying bacterial community, a combination of cultivation (screening and isolation) and cultivation-independent methods targeting different enzymes of the denitrification process were used. In addition to selective cultivation the abundance of denitrifying bacteria was studied by a real-time PCR approach quantifying the nitrite reductase (*nirK*) and the nitrous oxide reductase (*nosZ*) genes. Results of both methods demonstrated only a marginal effect on the abundance of this functional group. The analysis of the community structure of denitrifying bacteria was performed by cultivation under selective conditions, physiological tests of the isolates and their phylogenetic assignment. In parallel, the community structure was studied by a *nirK* clone library. In contrast to the abundance of the *nirK* and *nosZ* genes, both the composition of the isolates as well as the cloning approach revealed a long-term effect of N-fertilization.

The results show clearly that the combination of different experimental approaches can actually

lead to a better understanding of the N turnover and loss processes of fen peatlands.

2.15. Soil fluxes of carbon dioxide, nitrous oxide, and methane in a southern Portugal evergreen oak forest

Lobo do Vale, R., Shvaleva, A., Castaldi, S., Carfora, A., Rosa, A.P., Cruz, C., Chaves M.M., Pereira J.S.

Contact: Raquel Lobo do Vale (raquelvale@isa.utl.pt)

During the past century, annual mean temperature has increased by 0.75°C and precipitation has shown marked variation throughout the Mediterranean basin. Recent changes in climate may have had significant, but presently not enough defined, impacts on water-use efficiency, structure, productivity and, generally, on Mediterranean ecosystems functioning. The aim of the work was to assess how do external drivers (season, soil temperature and soil water content) affect the greenhouse gases (GHGs), i.e. CO₂, N₂O and CH₄ fluxes in southern Portugal. The region has typically Mediterranean climate, with a hot and dry summers and cool humid winters, with annual precipitation ca. 669 mm.

Soil CO₂ emission and CH₄ and N₂O fluxes were collected during April, 2008-June, 2009 and cover the annual cycle and provide measurements at key events of particular importance for the exchange of GHGs at the ecosystem. Soil temperature and soil moisture were monitored simultaneously when the gas samples were collected. Our results showed that two factors soil moisture and soil temperature are important variables controlling CO₂ emission rates in Mediterranean forest ecosystems. It is believed that increases of soil water content after summer drought can increase soil CO₂ efflux because of increased soil heterotrophic respiration as a result of stimulation of microbial activity and of structural alterations in soil micro- and macro-aggregates. For N₂O and CH₄ we did not find any significant relationship to soil temperature and soil moisture, as well as no significant correlation between N₂O and CH₄ was found.

2.16. N₂O Fluxes in a steppe environment as affected by grazing and manure management

Wolf, B., Chen W., Zheng, X., Brüggemann, N., Butterbach-Bahl, K.

Contact: Benjamin Wolf (benjamin.wolf@imk.fzk.de)

2.17. Simulation of N₂O emissions from productive grasslands in response to changes in management, climate and botanical composition

Calanca, P., Neftel, A.

Contact: Pierluigi Calanca (pierluigi.calanca@art.admin.ch)

As much of the world's grasslands are botanically diverse, the impacts of changes in climate and management on the C and N cycling ultimately depend on the differential response of functional groups within the sward. This holds true also with regard to the exchange of gaseous N compounds. Results from field experiments suggest, in particular, that N₂O emissions from fertilised lays vary considerably with clover abundance. Therefore ability to realistically simulate the latter is essential for obtaining reliable predictions of the former under climate change and management scenarios. In this contribution we examine N₂O emissions from fertilised grasslands on the basis of simulations with the PROductive GRASSlad Simulator (PROGRASS), a model specifically developed to account for grass/clover interactions in mixed swards. After showing that the model is able to capture emission peaks following fertilization at sites from the NitroEurope monitoring network, we explore the sensitivity of the N₂O flux with respect to changes in the fertilisation regime and ensuing shifts in clover abundance. We further address the question of long-term shifts in botanical composition from the perspective of climate change. The implications of these results for the definition of an N₂O emission factor are discussed.

3. Plot scale modelling of processes controlling the biosphere-atmosphere exchange of trace gases to predict effects of changes in climate, land use and land management on gas exchange of C and N compounds

3.1. Accounting for slurry infiltration and surface crusting in mechanistic modeling of ammonia volatilization after slurry spreading: Application to the Volt'Air model

Garcia, L., Générumont, S., Bedos, C., Garnier, P., Cellier, P.

Contact: Luid Garcia (lgarcia@grignon.inra.fr)

Several mechanistic models have been developed to simulate ammonia volatilization after surface slurry spreading (van der Molen et al., 1990; Générumont and Cellier, 1997; Wu et al., 2003; Beuning et al., 2008), but none of them successfully managed to realistically represent (i) slurry infiltration into the soil which fixes the availability of ammoniacal-N for volatilization, (ii) the development of an interface submitted to rapid drying/rewetting events highly influencing the physical conditions (temperature and humidity) which in turn determine volatilization, and (iii) slurry surface crusting which is known to significantly reduce volatilization.

To account for the physical influences of slurry on the surface, and consequently on the volatilization flux, it is proposed to add a layer of slurry at the surface of the soil. It is hypothesized that the slurry layer is proportional to the application rate and can be assimilated to a soil layer at the hydrological point of view, and characterized by its specific hydraulic

parameters (Génermont et al. submitted). As Garcia et al. (submitted) showed that a very thin surface layer is needed to finely represent the dynamics of drying and rewetting events at hourly time scales, it is also proposed to divide the slurry into two layers, the one at the interface with the atmosphere being very thin.

In order to evaluate these assertions, they were implemented in the mechanistic volatilization model Volt'Air (Génermont and Cellier, 1997; Garcia et al., submitted). This gave 3 configurations: (i) the "Slurry Mixed into the soil" configuration (MS), (ii) the "single Slurry Layer" configuration (1SL) and (iii) the "dual Slurry Layer" configuration (2SL). The assessment has been established through (i) a sensitivity analysis and (ii) comparisons with measurements of ammonia volatilization fluxes (instantaneous and cumulative) and ammoniacal nitrogen distributions in the soil. The improvement gained by the addition of one, and even more by two, slurry layer(s) in the description of slurry infiltration allowed avoiding calibration for volatilization calculations. Crusting can be represented too, but further characterizations may be necessary. This approach revealed to be promising for being extended to all kinds of organic materials present at the soil surface.

3.2. Application of the rule-based hybrid model B-LINE 2 to modelling of N₂O emissions from imperfectly drained N-fertilised grassland soils and buffer strips

Smith, K., Massheder, J., Reay, D., McAuley, L.

Contact: Keith Smith (keith.smith@ed.ac.uk)

In view of the spatial and temporal variability in N₂O emissions from N-fertilised agricultural soils, it has been difficult to predict those emissions solely by means of mechanistic models. As an alternative approach, a relatively simple rule-based/ boundary line procedure was developed to predict emissions from grassland soils in Scotland on the basis of measured variables: soil water, temperature and mineral N content (Conen et al, 2000). This procedure was further developed into a hybrid model in which these principal drivers were themselves modelled, with a daily timestep, using established theory to calculate soil temperature and water status, and an empirical relationship for the decrease with time of soil mineral N after an application of N fertiliser, based on numerous field studies over several years. The resulting values for the driving variables were then integrated with the rule-based procedure to create a hybrid model that successfully predicted fluxes with annual emission factors varying nearly 20-fold (Smith et al, 2004). This model (now called B-LINE 2) has now been further refined, as part of the NitroEurope project, and is being applied to simulate the N₂O emissions from a buffer strip frequently flooded with nitrate-rich agricultural drainage water, and also to simulate the ratio of N₂O to N in the products of denitrification and hence the total amount of denitrification taking place. The paper will present the results obtained in this simulation and discuss the more general applicability of the model to agricultural environments.

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3.3. Predicting and mitigating the global warming potential of agro-ecosystems

Lehuger, S., Benoit, G., Laville, P., Lamboni, M., Chaumartin, F., Bessou, C., Cellier, P., Loubet, B.

Contact: Simon Lehuger (Simon.Lehuger@grignon.inra.fr)

Nitrous oxide, carbon dioxide and methane are the main biogenic greenhouse gases (GHG) contributing to the global warming potential of agro-ecosystems. Evaluating the impact of agriculture on climate requires a capacity to predict the net exchanges of these gases in an systemic approach, as related to environmental conditions and crop management. Here, we used experimental data sets from intensively-monitored cropping systems of the NitroEurope-IP network to calibrate and evaluate the ability of the biophysical crop model CERES-EGC to simulate GHG exchanges at the plot-scale. The experiments involved major crop types (maize-wheat-barley-rapeseed-sugar beet) on loam and rendzina soils. The model was subsequently extrapolated to predict CO₂ and N₂O fluxes over entire crop rotations. Indirect emissions arising from the production of agricultural inputs and from use of farm machinery were also added to the final GWP. Nitrate leaching, nitric oxide emissions and ammonia exchanges were also computed by the model and were used to estimate the downstream indirect N₂O emissions. One experimental site (involving a wheat-maize-barley rotation on a loamy soil) was a net source of GHG with a GWP of ~670 kg CO₂-C eq ha⁻¹ yr⁻¹, half of which were due to upstream indirect emissions and half to direct N₂O emissions. The other site (involving a rapeseed-wheat-barley rotation on a rendzina) was a net sink of GHG for ~650 kg CO₂-C eq ha⁻¹ yr⁻¹, mainly due to a higher predicted C sequestration potential and C return from crops. Such modelling approach makes it possible to test various agronomic management scenarios, in order to design productive agro-ecosystems with low global warming potential. The model should be extrapolated from plot- to regional-scale, with the ultimate goal to generate spatialized GHG inventories. Differentiating the emissions in space would thus make it possible to target critical zones in mitigation scenarios at regional scale.

3.4. Simulating soil N₂O and CO₂ emissions from arable organic and conventional systems using two biogeochemical models

Chirinda, N., Kracher, D., Lægdsmand, M., Porter, J., Olesen, Petersen, M., Kiese, R., Butterbach-Bahl, K.

Contact: Ngonidzashe Chirinda (Ngonidzashe.Chirinda@agrsci.dk)

Biogeochemical models are important tools for improving our understanding of underlying processes that regulate emission of greenhouse gases from soils. However, the modelling of soil

nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions is challenging due to complex interactions of soil physical and biochemical properties that influence the production and transport of these gases. The objective of this study was to simulate soil N_2O and CO_2 emissions from three different organic and one conventional cropping system using two different one-dimensional, process-oriented, biogeochemical models. The simulations from the two models were validated against multiple field measurements made in winter wheat plots from four different cropping systems within a long-term experiment in Denmark. For this study, we used the Modular Biosphere Simulation Environment (MoBiLE) framework and the Farm ASSESSment Tool (FASSET). In the MoBiLE framework, different sub-modules were used for simulation of ecosystem carbon and nitrogen turnover and biosphere-atmosphere exchange. Specifically, sub-modules for soil physics, water cycling and biochemistry as originating from the PNET-N-DNDC model were coupled to crop growth and management sub-models of the DNDC model; the resultant model is known as MoBiLE-DNDC. For the second model, FASSET, the soil-plant-atmosphere sub-models were used. Despite other discrepancies, these two models use different algorithms to simulate soil N_2O production: MoBiLE-DNDC uses the “anaerobic balloon” concept, while FASSET makes use of semi-empirical functions. Winter wheat growth parameters were slightly modified in MoBiLE-DNDC. No calibration of the FASSET model was performed. MoBiLE-DNDC showed several limitations in accurately predicting daily soil N_2O and CO_2 emissions. Nevertheless, annual cumulative N_2O ($1.1\text{--}1.3 \text{ kg N}_2\text{O-N ha}^{-1}$) and CO_2 ($2891\text{--}3543 \text{ kg CO}_2\text{-C ha}^{-1}$) emissions from MoBiLE-DNDC were similar to those estimated from field measurements which, respectively, ranged between $0.6\text{--}0.9 \text{ kg N}_2\text{O-N ha}^{-1}$ and $3173\text{--}4578 \text{ kg CO}_2\text{-C ha}^{-1}$. The FASSET model satisfactorily simulated daily soil CO_2 emissions but also showed limitations in modelling daily soil N_2O emissions. Simulated annual soil CO_2 and N_2O emissions, from the FASSET model, that correspondingly ranged between $3454\text{--}5356 \text{ kg CO}_2\text{-C ha}^{-1}$ and $1.1\text{--}7.0 \text{ kg N}_2\text{O-N ha}^{-1}$, were both higher than annual emissions estimated from field measurements. The two models resulted in satisfactory simulations for soil $\text{NH}_4\text{-N}$ content but faced challenges in modelling $\text{NO}_3\text{-N}$, crop growth and nitrogen uptake in several cropping systems. We anticipate that improvements in modelling $\text{NO}_3\text{-N}$ will enhance modelling of N_2O emissions, crop growth and nitrogen uptake. Furthermore, with MoBiLE-DNDC, an increased rate of soil heterotrophic CO_2 respiration will probably enhance carbon availability for microbial activity and, consequently, improve simulations of soil N_2O and CO_2 emissions.

3.5. Predicting N_2O emissions from grassland: a comparison of DayCent and DNDC

Topp, K., Yeluripati, J., Rees, J.M.

Contact: Kairsty Topp (Kairsty.Topp@sac.ac.uk)

In 2003, Scottish agriculture was responsible for 83% of the N_2O emissions, which is mainly associated with the use of organic and inorganic fertilisers on grasslands. Nevertheless, grasslands tend to have a high CO_2 sink strength and therefore often act as net greenhouse gas sinks. Improved grasslands occupy a significant part of the Scottish landscape covering about 22% of the agricultural land area in 2005, and are associated with high organic C

concentrations. The manure and inorganic fertiliser management of these grasslands is known to have a significant impact on their N₂O emissions and hence greenhouse gas balance. Measurements of C storage in soils and C exchange can be made; however, they are technically demanding and difficult to repeat at a wide range of soil types, locations and management systems. Hence, it is essential that dynamic and deterministic models are developed and validated against existing experiments so that predictions can be made with regards to the greenhouse gas emissions both for current and future climatic conditions. Such models are useful to elucidate the interplay of different processes and their interactions, and thus formulate better strategies for reducing the emissions or enhancing the sinks of greenhouse gases of grasslands. In this paper, the predictions made by DNDC (Li et al., 1992, Li et al, 2006) and DAYCENT (Parton et al., 1998) have been compared for an experiment that was carried out on a grassland field in eastern Scotland. The treatments compared were ammonium nitrate and cattle slurry, which were applied at a rate of 300 kg N ha⁻¹, and a control treatment. The fertiliser and manure was applied for 2001-2002, and measurements were made for 2002-2004. The models have been compared for their ability to predict grass yield, the soil water profile, CO₂ and N₂O emissions over the measurement period.

3.6. Using the *ecosys* mathematical model to simulate topographic effects on spatial variability of nitrous oxide emissions from a fertilized agricultural field

K.A. Metivier¹, R.F. Grant¹ and E. Pattey²

1. Department of Renewable Resources, University of Alberta, Canada T6G 2E3 and

2. Eastern Cereal and Oilseed Research Centre, Agriculture and Agri-Food Canada, Ottawa K1A 0C6

Contact: Robert Grant (Robert.Grant@ales.ualberta.ca)

Calculation of emission factors (EFs) for nitrous oxide (N₂O) is complicated by their large spatial variability. The objective of this study was to test the hypotheses that spatial variation in N₂O emissions can be explained by (1) spatial and temporal variation in soil water-filled pore space (WFPS) among topographic positions that shed or collect water according to topographically-driven water movement, and (2) spatial variation in soil properties which may themselves be caused by topographically driven water movement. These hypotheses have been incorporated into a detailed processed-based, three-dimensional mathematical model of terrestrial ecosystems, *ecosys*. We simulated emissions using *ecosys* at different spatial scales – meter, fetch and field, using a 20 x 20 matrix of 36m x 36m grid cells from a digital elevation model (DEM) to represent topography of a fertilized agricultural field in Ottawa, Canada. Modeled results were compared to fluxes measured with chambers placed at different topographic positions to measure spatial variability of N₂O emissions at the meter scale, and with stationary and mobile flux towers with tunable diode lasers (TDL) and a flux-gradient technique to assess spatial N₂O variability at the fetch scale. Most modeled and measured emissions occurred during a 10-day interval in late spring/early summer, due to a combination of fertilizer N application, rainfall and rising soil temperatures. Coefficients of spatial variation (CSVs) measured amongst 4 chamber replicates (2 x 3 m grid) during emission events were 28 to 195 %, indicating that spatial variation of N₂O occurs at a very small spatial scale. Annual

CSVs modeled at the field scale rose from 25% when soil properties in the model were assumed uniform to 101% when soil properties in the model were allowed to vary according to results from a field soil survey. The modeled EF (assumed uniform soil properties) for a fertilizer application of 112 kg N ha⁻¹ was larger in an area of the field with lower topography (0.3%) than in one with higher (0.1%). EFs were low compared to those of other studies because delayed spring warming in the year of study caused nitrification of fertilizer N to occur under lower temperatures than average for this site. These results show that hourly time-step 3-dimensional models such as ecosys used with input from DEMs can fully reproduce large spatial and temporal variability of N₂O from topographically-driven water movement at different spatial scales even in seemingly flat (0.2% slope) landscapes.

4. Up-scaling from plot to regional scales – analysing interactions on different spatial scales

4.1. Effects of spatio-temporal heterogeneity on modelling and upscaling agricultural N-losses and greenhouse gas emissions in European landscapes

Dalgaard, T., Dragosits, U., Hutchings, N., Olesen, J., Happe, K., Drouet, J.L., Cellier, P.

Contact: Tommy Dalgaard (tommy.dalgaard@agrsci.dk)

The aim of this study is to exemplify methods to model and upscale farm nitrogen (N) losses and greenhouse gas emissions, and assess the effects of spatio-temporal heterogeneity in European landscapes. The importance of handling landscape level spatio-temporal dynamics and the effect of structural changes are outlined with results from the EU funded research projects NitroEurope (www.NitroEurope.eu) and MEA-scope (www.MEA-scope.org). Especially, problems in integrating information from different scales in the modelling of landscape level farm N balances and greenhouse gas emissions are discussed. Results are exemplified with applications of the dynamic whole farm model FASSET (www.FASSET.dk), and the Farm-N tool (www.farm-N.dk/FarmNTool) to calculate farm N balances, and distribute the surplus N between different types of N-losses (volatilisation, denitrification, leaching), and the related greenhouse gas emissions in the NitroEurope component four study landscape in Denmark. Significant effect of non-linearities, appearing when scaling up from farm to landscape, are demonstrated; first in a simple study, where results from three synthetic farms are aggregated; and secondly in a complex study, where real farm data results from the Danish study landscape are aggregated. Based on this, general recommendations for landscape level modelling of farm related nitrogen and greenhouse gas fluxes are made, and discussed in the context of the planned NitroScape model exercise in all the NitroEurope component four study landscapes.

4.2. FARMSIM: an integrated tool to model greenhouse gas emissions at the farm level

Drouet, J.L., Duret, S., Fiorelli, J., Blanfort, V., Capitaine, M., Capian, N., Gabrielle, B., Martin, R., Lardy, R., Cellier, P., Soussana, J.

Contact: Jean-Louis Drouet (drouet@grignon.inra.fr)

Agricultural systems, especially livestock systems, are a large source of emissions of greenhouse gas (N₂O, CH₄, CO₂) and reactive nitrogen (NH₃, NO_x, nitrates). Mitigation options suggested in the literature mainly focused on a single gas and dealt with isolated processes. An integrated modelling tool was developed to assess the effect of farm practices on reactive nitrogen and greenhouse gas emissions at the whole farm level. It integrated the farm model

FARMSIM developed during the GreenGrass project (2002-2004) and using the IPCC methodology to simulate emissions from farm components (housing, manure management, livestock energy consumption). The FARMSIM model was coupled with two process-based models of ecosystems: the cropland model CERES-EGC and the grassland model PASIM. Prior to model use to assess mitigation options, a sensitivity analysis was carried out to reduce the number of input factors to be measured or collected for model calibration. The model inputs were biophysical parameters (e.g., soil and vegetation parameters, emissions factors), farming practices (e.g., N management, grassland management, herd management, farm structure, land use change) and meteorological conditions. Simulated output variables were N_2O , CH_4 , CO_2 , NH_3 emissions. The reference farm was reconstructed from farming practices within an intensive dairy farm located in North-Eastern France (INRA Mirecourt, Lorraine). Several statistical methods were implemented to classify input factors (Morris method), identify interactions between input factors (rank-based methods) and analyse the uncertainty of simulated variables (Fourier-based method). First results showed the relevance of such methods to assess the effect of input factors e.g., soil biophysical properties, farm N management, herd structure on gas emissions. That forms a preliminary study to the assessment of mitigation options integrating national and European policies as well as farmers decisions.

4.3. NitroScape: an integrated model of nitrogen fluxes and transformation at the landscape scale

Duret, S., Drouet, J.L., Durand, P., Hutchings, N.J., Theobald, M.R., Dragosits, U., Salmon-Monviola, J., Maury, O., Sutton, M., Cellier, P.

Contact: Silvia Duret (sduret@grignon.inra.fr)

Indirect emissions of nitrous oxide (N_2O) are estimated to be around 20% of the total N_2O emissions of European Union. These emissions are strongly related to the short-range transfer of nitrogen (N) in the hydrological network or the atmosphere. Since N transfers are strongly related to topography, spatial distribution and surface characteristics, the landscape scale is highly relevant to assess both direct and indirect N_2O emissions. The NitroScape model is developed to assess a landscape N budget that includes indirect emissions of N_2O . This model integrates the different pathways of N transfer and transformations in the landscape: emissions from ecosystems and livestock buildings, atmospheric transfer and short-range deposition, biological transformations of N in the ecosystem, transfer through the hydrological pathways and N transfer within farms. NitroScape integrates existing models for each component of the system: atmosphere, ecosystems, hydrological networks and farm buildings. Since processes involved in each component are strongly interdependent, each component model is dynamically coupled with the other models using the dynamic coupler PALM. NitroScape integrates distributed models taking into account spatial data provided by a GIS in order to deal with spatial distribution and heterogeneity of land uses and soil properties. NitroScape calculates the N-budget of a landscape providing direct and indirect N emissions to the atmosphere, N loss to freshwater and N storage. NitroScape will be calibrated and evaluated from data collected on six European landscapes. NitroScape will then be used to assess (i) the impact of short-range transfer on landscape N budgets and (ii) the sensitivity of the model to landscape structure, distribution and heterogeneity. By running scenarios, NitroScape will also be suitable for

assessing the impact of European directives on the N budgets of European landscapes.

4.4. MoBilE2D: The Regionalization of the Modular Biosphere Simulation Environment - Concept, Regional Application and Future Plans

Haas, E., Werner, C., Butterbach-Bahl, K.

Contact: Edwin Haas (edwin.haas@imk.fzk.de)

Regionalization of greenhouse gas (GHG) emissions and nitrate leaching rates for regional assessments and inventories have been previously performed by subdividing the regional domain of interest into units representing homogeneous conditions i.e. homogeneous simulation response units (HSRUs) (Kesik et al., 2006; Werner et al., 2007, Butterbach-Bahl et al., 2009). Model input data on the level of HSRUs was created by coupling the site scale ecosystem Models (like DNDC or MoBilE-DNDC) to a GIS database holding (spatially distributed) all relevant parameters for model initialization (soil and vegetation properties) and driving forces (climate, land management data). Based on scenario analysis, different land use strategies and/or feedbacks of GHG exchange to climate change can be explored (Kesik et al., 2006) using this approach. A typical regional DNDC/MoBilE-DNDC applications based on 1000 HSRUs easily create several hundred thousands of single files during the execution of the regional simulation. Even for modern computer systems, this amount of files – often holding only minor information – states a fundamental problem of this approach and limits the performance of the regionalization.

To overcome this problem and to launch new possibilities in the simulation of C & N cycles coupled to hydrological nutrient transport on the landscape and regional scale, the site scale simulation environment MoBilE-DNDC was extended to two dimensions. In the process of regionalization, MoBilE2D operates on a computational grid. Therefore the area of interest has to be divided into regular grid cells (chessboard style grids) or into irregular shaped grid cells (triangulation by polygons). MoBilE2D incorporates the MoBilE-DNDC core (which is identical with the site scale model) into each grid cell and allows two modes of operation: (i) The sequential regionalization mode in which MoBilE2D performs the simulation of the individual grid cells sequentially. This operational mode reduces the necessary amount of files to handle down to a few, enables the direct coupling of the simulation system to the GIS database or to a relational database system holding all input and output data. This approach reduces the pre- and post-processing effort for the regionalization substantially. In the (ii) synchronous regionalization mode, MoBilE2D performs the integration of all grid cells synchronously time step by time step. This mode enables the coupling of MoBilE2D to other simulation systems (like hydrology, air chemistry and dispersion, meteorology and regional climate) and the exchange of states between the systems resulting in the overall simulation of feedback mechanisms between the compartments. This is a fundamental property of any geochemical model to be integrated into the NitroScape Model.

As MoBilE2D is fully parallelized, it takes advantage of modern MultiCore Computers as well as High Performance Computing systems (HPC). Substantial speedups of the regionalization (in sequential as well as in synchronous mode) can be achieved which opens new fields of

applications as well as possibilities like the assessment of regional sensitivity, which have been limited in the past. A first application of MoBiE2D will be presented. The focus will be a regional N₂O and NO emission inventory from agricultural and forest ecosystems on the regional scale. Besides the GHG emissions, the speedup of MoBiE2D regionalization compared to the previously used approach will be discussed as well as examples of model coupling on the regional scale.

4.5. Integrated analysis of the effects of agricultural management on environmental quality at landscape scale

Kros, J., Frumau, K.F.A., Hensen, A., de Vries, W.

Contact: Hans Kros (Hans.Kros@wur.nl)

Farmers in the so-called Noordelijke Friese Wouden (NFW), an area in the northern part of the Netherlands, have a long history in developing and exploring alternatives for intensive dairy farming, to avoid its negative environmental impacts. Joined together in an environmental cooperative, farmers have lowered both Nitrogen and Phosphorus losses by changing farm- and field management from the 1990's onwards. The cooperative has recently made an agreement with the government about achieving environmental quality and emission objectives at regional level rather than at farm level. Hence, the cooperative itself will decide which measures the farmers will implement. To gain insight in the impact of different manure application techniques, ammonia concentrations were monitored to gain insight in the impact of application techniques on ammonia emissions.

To gain insight in the environmental impacts of manure and fertilizer applications in the NFW area, an integrated model system INITIATOR2 (Integrated Nutrient Impact Assessment Tool On a Regional scale) was applied predicting: (i) emissions of ammonia and greenhouse gases (CO₂, CH₄ and N₂O) from animal housing systems and agricultural soils and (ii) leaching and runoff of nutrients (specifically nitrogen and phosphorus) from agricultural soils to ground water and surface water.

This presentation provides an application of INITIATOR2 to assess the impacts of present agricultural land use in the NFW, using spatially explicit high quality input data on agricultural practice, land management, meteorology etc. An analysis of strengths and weaknesses this approach including a comparison with observation based ammonia emission estimates will be presented. In addition, the impacts of various measures with a focus on the reduction of ammonia emission are evaluated, including their cost-effectiveness. Evaluated measures were amongst others (i) emission reduction from poultry and pig housing system by using air washers, (ii) low protein feeding, (iii) reducing fertilizer amount and (iv) conversion towards biological dairy farms.

4.6. Estimation of N₂O emission factors for soils depending on environmental conditions and crop management

Lesschen, J.P., Velthof, G.L., Kros J., de Vries, W.

Contact: Jan Peter Lesschen (janpeter.lesschen@wur.nl)

Nitrous oxide (N₂O) contributes 8% to anthropogenic global warming, of which about one third are direct emissions of agricultural soils. These N₂O emissions are often estimated using the default IPCC 2006 emission factor of 1% of the amount of N applied for mineral fertilizer, manure and crop residues. However, a large variation in emission factors exists due to differences in environment (e.g. weather and soil conditions), crops (grassland, arable land, crop residues) and management (e.g. type of manure and fertilizer, application rates, time of application). We developed a simple approach to determine N₂O emission factors that depend on environmental, crop and management factors.

The main factors controlling N₂O emission are nitrate content, oxygen content, available C content, temperature and pH. The starting point of the method was a two-year monitoring study of Velthof et al. (1996), who found an emission factor of exactly 1% for grassland on a sandy soil fertilized with calcium ammonium nitrate. The conditions of this experiment were set as the reference from which the effects of other environmental conditions and management on the N₂O emission factor were estimated. Based on literature and expert knowledge we determined for 19 sources of N input, three soil types, two land use types, three precipitation classes, two pH classes and three temperature classes the effect on the default emission factor. The calculated N₂O emission factors ranged from 0 to 10%.

The approach was applied to a European scale, using the INTEGRATOR model. The results were also produced with the standard IPCC approach and the empirical approach by Stehfest and Bouwman (2006). Differences in the overall results at EU27 scale and at regional scale are discussed. The emission factors derived from this inference scheme can improve predictions of N₂O emissions with integrated large-scale models.

4.7. Farm, Land, and Soil nitrogen budgets for Agriculture in Europe

Leip, A., Weiss, F., de Vries, W.

Contact: Adrian Leip (adrian.leip@jrc.ec.europa.eu)

Nitrogen surplus is an important indicator to describe the pressure that agriculture puts on the environment, particularly water pollution. The OECD and EUROSTAT developed a methodology to estimate national 'gross nitrogen balances', which are used to measure progress with two EU-directives: the Nitrate Directive (91/676/EC) and the Water Framework Directive (2000/60/EC). They are calculated as the difference between the total quantity of nutrient inputs entering an agricultural system, and the quantity of nutrient outputs leaving the system. The boundaries of this approach is the "land" in general as only crop and pasture products are accounted for in the outputs and manure is accounted for as a whole in the inputs. We therefore

define the OECD-gross N-balance as “Land N-budget” which differs from the “Farm N-budget” or the “Soil N-budget”. In the Farm N-budget, manure is considered as internal recycling of nitrogen (throughput), if not in- or exported from the farm, and animal products are considered as N-outputs. In the “Soil N-budget” only the fraction of nitrogen in manure is considered, that is applied on soils or deposited by grazing animals.

The differences in the N-budgets are not only the consequence of model design: the land N-budget is most easily calculated from national statistics and excretion factors, while additional economic information is required for the farm-N budget and N-losses from manure before in animal housing and manure management systems must be estimated for the soil N-budget. The N-budgets serve also different purposes: while the land N-budget gives a good indication of the overall agricultural emissions, the soil N-budget serves for estimating N-efficiency in crop production. In contrast, the farm N-budget can be used to assess the N-efficiency of the society. We use the CAPRI model to estimate Farm, Land, and Soil N-budgets for countries in Europe and the EU27 as a whole. We present results both in term of total N-surplus and differentiated into the individual Nr loss fluxes (NH_3 , N_2O , NO_x , N leaching and runoff). The calculated N-surplus increases from Soil (6.4 Mt N y^{-1}) over Land (9.0 Mt N y^{-1}) to Farm (13.3 Mt N y^{-1}) N-budgets showing that animal production systems have a by far lower nitrogen efficiency (24% for the farm N-budget) than crop production systems (66% for the soil N-budget).

4.8. Spatio-temporal development of C and N export in two upland Scottish streams and its relationship to catchment characteristics

Engeland, C., Breuer, L., Dragosits, U., Vogt, E., Braban, C.

Contact: Christian Engeland (Christian.Engeland@agrar.uni-giessen.de)

Despite efforts to relate nitrogen (N) concentrations and loads in streams to land use, catchment characteristics and climate, uncertainty still remains on the effective controlling mechanisms of catchment scale N losses. This is mainly due to the large variability of catchment systems (e.g. hydrological processes and flow paths) and the many chemical forms of N. Dissolved inorganic N (DIN) species include NO_3^- , NO_2^- and NH_4^+ and organic nitrogen is measured as dissolved organic N, (DON), being the difference between measured total-N (TN) and DIN. This project investigates the interdependence of the controlling mechanisms of N export by measurements and landscape observations.

Two streams have been studied in a rural landscape in Southern Scotland. Land use differs between the two streams: one catchment includes mainly peatland and low intensity agriculture and the second catchment is a more intensively managed agricultural catchment (beef cattle, sheep farming and poultry farms). Each of catchments cover approximately 7 km^2 . The temporal and spatial changes in TN, DON, DIN (as NO_3^- and NH_4^+), DOC, 2H/H and 18O/16O were measured. Stream parameters including conductivity and pH were also investigated. Two temporal scales were studied at the catchment outlets: a) continuous time series (3 samplings per day) for 2 months and (b) high temporal resolution storm event sampling (1 sample per 60 min). Spatial sampling covered c. 35 points along each stream catchment.

Initial results have showed large differences for NO_3 , DOC, conductivity and pH between the two streams, however ammonium is relatively low in both streams. The reasons for these

differences will be investigated and discussed in this paper. The underlying hypothesis is that the land-use and soil type can account for the observed variations. This will be investigated by integrating the chemical and isotopic information obtained.

5. Assessment of present and future nitrogen and green house gas fluxes at large regional scales in response to human influence

5.1. Bayesian inversion for N₂O fluxes using a global data set

Thompson, R. L., Bousquet, P., Chevallier, F.

Contact: Rona Thomson (rona.thomson@lsce.ipsl.fr)

Atmospheric nitrous oxide (N₂O) concentrations have been increasing steadily since the industrial revolution, and because N₂O is a potent Greenhouse Gas (GHG), this increase translates into an enhancement in radiative forcing. Currently, N₂O is the fourth most important long-lived greenhouse gas but it is predicted to soon overtake CFC's to become the third most important. In addition, N₂O plays an important role in stratospheric ozone chemistry.

Despite the importance of N₂O as a GHG, emission estimates have been hitherto poorly constrained. This has partly been due to a paucity of available measurements of fluxes as well as of atmospheric mixing ratios. However, recently there has been a significant increase in the availability of atmospheric data facilitating the constraint of N₂O emissions using an inversion model.

We present the results of a bayesian inversion of a global dataset of N₂O mixing ratios including flask and in-situ observations. For atmospheric transport, we use the LMDZ model with a zoom of 1 x 1 degree over Europe. The cost function minimum is found iteratively using the conjugate gradient method. Posteriori emission estimates are shown at monthly resolution for 2006 – 2007 along with their validation against independent atmospheric observations, which were not used in the inversion.

5.2. Effect of historical changes in land-use, N fertiliser application and atmospheric N deposition on terrestrial carbon and nitrogen fluxes

Zaehle, S., Friedlingstein, P., Friend, A.D., Prieur, V., Schulz, M.

Contact: Soenke Zaehle (soenke.zaehle@bgc-jena.mpg.de)

We present a first estimate of the consequences of historical anthropogenic perturbations of the terrestrial carbon and nitrogen balances due to land-use changes, increases in N fertiliser application and atmospheric N deposition. These changes are evaluated relative to a baseline simulation taking historical climatic changes and increases in atmospheric CO₂ concentrations into account. The estimates are obtained using the global, process-based terrestrial ecosystem model O-CN, which encodes a mechanistic understanding of the coupling between terrestrial C and N dynamics for twelve global vegetation types. In particular, O-CN estimates N trace gas

emissions using a process-based approach. Evaluation exercises show that the simulated effect of N additions on vegetation productivity and net C storage agrees well with observations from a range of field studies and manipulation experiments. N trace gas emissions fall well within the observed ranges for individual vegetation types and global biomes, however, site-scale analyses reveal model deficiencies in capturing the temporal dynamics of NO and N₂O emissions. These are mostly related to the simplified treatment of soil hydrology in O-CN. Based on our global modelling results we identify key important processes and regions for which further observations, as well as model development and validation work are required to provide a comprehensive assessment of the effect of anthropogenic activities on nitrogen controlled greenhouse gas balances.

6. Verification and uncertainty assessment of N and GHG management across disciplines

6.1. Geostatistical simulation of European soil property maps

Heuvelink, G., De Vries, W., Kros, H., Reinds, G.J.

Contact: Gerard Heuvelink (gerard.heuvelink@wur.nl)

A geostatistical model was developed and applied to predict five basic soil properties for three soil horizons at the European scale and quantify the associated prediction uncertainties. The five soil properties are pH, organic carbon, organic nitrogen, clay content and bulk density. The geostatistical model takes a regression cokriging approach, in which correlations between soil properties and across soil horizons are taken into account. Non-stationarities in the means and variances are represented by mapping units of the generalized European soil and land cover maps. The model was calibrated using the WISE/SPADE database, which contains approximately 1,200 observations, irregularly distributed over Europe. The resulting model showed for most soil properties strong dependencies on soil type and land cover, moderate correlations between soil property residuals, strong correlations across horizons, and moderate spatial correlation of the regression residuals. Conditional sequential Gaussian simulation was used to generate possible realities of the soil properties on a 5 km by 5 km grid. Uncertainties in the resulting maps are large, particularly in undersampled parts of Europe and in strata with large spatial variation. Validation with independent data from a small part of Europe (i.e., the Netherlands) showed that the uncertainties were realistically assessed. We conclude that geostatistical modelling and simulation are useful techniques to quantify uncertainties in soil property maps at the European scale. These techniques deliver the input needed for Monte Carlo uncertainty propagation analyses of spatially distributed dynamic models. In particular, the results of this study will be used to analyse how uncertainty in soil properties propagates through terrestrial greenhouse gas emission models developed and applied in the NitroEurope project.

6.2. Comparison of land nitrogen budgets for European agriculture by various modeling approaches

De Vries, W., Leip, A., Reinds, G.J., Kros, J., Lesschen, J.P., Bouwman, A.F.

Contact: Wim De Vries (wim.devries@wur.nl)

A comparison N budgets for the year 2000, including key N fluxes N (NH_3 , N_2O and NO_x emissions and N leaching/ runoff from housing and manure storage systems and soils), of agroecosystems is made for the EU 27 countries by using 4 models, i.e. INTEGRATOR, CAPRI-

DNDC, MITERRA and IMAGE, with different complexity and data requirements. A description is given of models used and their data inputs. Results then include tables of N budgets for all the EU 27 countries, at country level and maps of the key N fluxes over Europe using the geographic resolution of each model, to give insight in the impact of spatial aggregation on N fluxes.

For EU27, the models estimate a total N input in European agriculture of, which is mainly due to fertilizer and animal manure inputs and to a lesser extent by atmospheric deposition and N fixation. Total N inputs including fertilizer and animal manure inputs, atmospheric deposition and N fixation, at EU 27 level are comparable for all models (23.9 - 25.6 Mton N.yr⁻¹), since all models use comparable basic data on fertilizer use and animal numbers. The N uptake varies from 11.3 - 13.5 Mton N.yr⁻¹ leading to total N surpluses varying from 11.7 - 13.4 Mton N.yr⁻¹ at EU27 level. Results for the year 2000 indicate that a maximum N application rate by animal manure of 170 kg N (with derogations of 250 kg N for the Netherlands and 230 kg N for Denmark, Germany and Austria) is only exceeded in very few areas.

The various models also give similar results for the emissions of NH₃ (2.8 – 3.9 Mton N.yr⁻¹) and N₂O (0.35 – 0.46 Mton N.yr⁻¹) but vary largely for NO_x (0.02 - 0.20 Mton N.yr⁻¹). In non-agricultural systems, estimated emissions are approximately ten times as low for N₂O and 5 times as low for NO_x. Estimated total N leaching and runoff from agro-ecosystems by the various models vary by a factor 2 from 2.7 - 6.3 Mton N.yr⁻¹, while the value is approximately ten times as low for non-agricultural systems. The number of countries with estimated NH₃-N emissions exceeding the National emission ceilings for 2010, depends on the model approach and varied between 5 and 18, while the total exceedance varied between 62 and 1287 kton NH₃-N.

A comparison of agricultural emissions of NH₃-N, N₂O-N and NO_x-N for all the 27 EU countries for the year 2000 as derived with the four complete N balance models and several standard activity data-emission factors approaches (UNFCC/IPCC, GAINS, OECD, EDGAR and EMEP) shows comparable estimates for NH₃, which is due to the use of comparable databases for the estimation. The differences in N₂O emissions, however, are much larger, while NO_x emissions are most uncertain.

6.3. Modelling greenhouse gas emissions at the European scale using upscaling of selected areas and full aerial support

Reinds, G.J., Heuvelink, G. M., Hoogland, G., Kros, J., de Vries, W.

Contact: Jan Gert Reinds (gertjan.reinds@wur.nl)

A Monte Carlo uncertainty quantification/uncertainty analysis (UQ/UA) of complex dynamic greenhouse gas emission models used within the NitroEurope Integrated Project cannot be done for all 40,000 mapping units within Europe. This would be too computationally demanding. Therefore it was decided that the UQ/UA is only carried out for a sample of 450 locations within Europe. The UQ/UA results can be scaled up to the whole of Europe provided the sample of locations is chosen using probability sampling. In this paper, a comparison is made between upscaled model results from 450 selected locations within Europe and the whole of Europe, using the model INTEGRATOR. This shows whether a reliable estimate of the total European greenhouse gas emission can be made by upscaling the results for the selected

locations.

To represent the entire EU, the sample of locations was selected using stratified random sampling. EU27 was divided in 150 strata, and within each stratum three locations were selected randomly. The strata were based on important environmental factors that are known to influence greenhouse gas emissions: (i) land use, divided in arable, grass and nature, (ii) N manure application and N from grazing, (iii) N fertilizer application, (iv) mean annual temperature, (v) total annual precipitation and (vi) soil texture, divided in sand, clay and peat. Hierarchical divisive cluster analysis was used to reduce the numerous combinations of environmental factors to 150. Since land use is considered a dominant factor, each final cluster was homogeneous with respect to land use. Wetlands were excluded (220 NCUs), and so were a few points with unrealistic manure application estimates. The plot selection approach, resulting strata and the selected 450 locations are presented. Furthermore, results on NH_3 , N_2O and NO_x emissions and N leaching/runoff obtained by applying INTEGRATOR to the entire EU27 are provided as well as upscaled results of the selected 450 sampling locations. Based on this comparison, the reliability of the sampling and upscaling procedure is discussed.

6.4. Inverse modeling of European CH_4 and N_2O emissions

Bergamaschi, P., Corazza, M., Vermeulen, A.T., Manning, A.J., Athanassiadou, M., Bousquet, P., Thompson, R., Heimann, M., Trusilova, K., Karstens, U., van Aardenne, J., Monni, S., Popa, E., Haszpra, L., Moncrieff, J., Neubert, R., Nisbet, E., Aalto, T., Meinhardt, F., Ries, L., Steinbacher, M., O'Doherty, S., Artuso, F., Piacentino, S., Dlugokencky, E.

Contact: Peter Bergamaschi (peter.bergamaschi@jrc.ec.europa.eu)

European emissions of CH_4 and N_2O are estimated for the years 2006 and 2007 using various independent inverse models. We use continuous observations from 12 European sites (including several tall towers), complemented by further European and global flask sampling sites. We will present first results from the ongoing comparison of the inverse models within NitroEurope, including different global / regional Eulerian and Lagrangian transport models and different inversion techniques.

Part B: Posters

1. Flux measurements of reactive nitrogen, pools and processes

1.1. Influence of frequency of measurement on estimates of mean N₂O emissions and their uncertainties under arable fields

Roussel, M., Laville, P., Leonard, J., Grehan, E., Mary, B.

Contact: Magali Roussel (magali.roussel@mons.inra.fr)

N₂O fluxes from cropped areas are known to be highly temporally variable and peaks of emission can be very sporadic. Therefore, providing precise estimations of N₂O fluxes depends on the ability to capture temporal (daily and seasonal) variations, and thus on the frequency of measurements. Nevertheless, methodology is diverse among N₂O studies, sampling frequency varying from several points per day to only few points per month. To our knowledge, only few studies have focused on the possible bias and uncertainty linked to the effect of decreasing the sampling frequency, from sub-daily to sub-monthly temporal scales. To achieve this, we have used five datasets of continuous N₂O emissions, obtained from two northern France fields equipped with automatic static chambers. These sites were characterized by different crops (maize or sugar beet) and soil treatments (compacted or uncompacted). Measurements were made during 170-250 days, in 2007 and 2008. Two sampling frequencies were applied according to the site: 4 or 16 measurements per day. The overall dataset gave a large range of daily N₂O fluxes (from -2 to 130 g N ha⁻¹ d⁻¹). Our results show a large hourly variability: N₂O fluxes followed diurnal cycles with a peak at 12h GMT. We have analysed the bias introduced by considering only midday fluxes to calculate average and cumulative emissions over the entire experimental period. This can lead to an overestimation of 30% of these estimates. Moreover, a lack of information to describe the seasonal variations has also a significant influence: a decrease in the number of measurements (from daily to sub-monthly) induced a large increase in the uncertainty of the N₂O flux estimates (average and cumulative). These results highlight the critical aspect of methodology in N₂O studies, and the requirement of a high sampling frequency to obtain accurate estimates of N₂O emissions.

1.2. Spatial variability of site properties, biomass and soil respiration at the Castellaro cropland site

Ferrè, C., Comolli, R., Colombo, R., Busetto, L., Bocchi, S., Manfredini, A., Duerr, M., Manca, G., Zenone, T., Seufert, G.

Contact: Guenther Seufert (guenther.seufert@jrc.ec.europa.eu)

The NitroEurope Level 3 cropland site Castellaro is a 28ha large uniform field in Castellaro de' Giorgi, Lomellina, Lombardy, Italy, which is under semi-permanent rice cultivation. The study

presented here aims at selecting plots for point measurements (soil trace gas fluxes, yield, LAI etc.) to be representative for the footprint area seen by the flux tower. Before the final definition of the experimental setup we selected a 35x35m grid resulting in 108 sampling points within a 9ha experimental field to represent the flux tower footprint. In spring 2006 we performed a soil coring at all 108 grid points for describing the variability of taxonomic and chemical soil properties. In the same grid system we analysed CO₂ respiration rates and biomass in 2006 (maize) and 2007 (rice). Rice biomass and yield was analysed immediately before harvest also in the years 2008 and 2009 in a sub-sample of the grid.

The spatial variability of all site parameters investigated appeared to be quite large in this gleysolic area originating from fluvial deposits. For example, soil organic carbon ranges at 1.0 - 3.3%, total N at 0.18-0.35%, available P at 0.6-4.3 mg/kg; the texture is characterised by variable contributions of 17-59% sand, 26-52% silt, and 15-30% clay. We used a correlation matrix and principal component analysis to check for correlations between the parameters investigated. Close relations exist between SOC, respiration, texture and pH. Soil respiration in different years showed a similar spatial pattern, independent from cultivation type. Maize biomass varied between 0.2 and 0.9 kg/m² and was mainly controlled by available P.

In conclusion, the study was crucial for selecting and assessing representative plots for point measurements; at the same time we learned a lot about main drivers of crop performance and related cycles of greenhouse gases under specific field conditions.

1.3. Evaluation of acetylene inhibition technique for total N-loss measurements in soils with high inorganic N supply

Felber, R., Butler, M., Cardenas, L., Conen, F., Jocher, M., Neftel, A.

Contact: Raphael Felber (raphael.felber@art.admin.ch)

Losses of nitrogen as N₂ constitutes a major fraction of the N-turnover in managed grassland systems and might be in the order of 30% of the applied N (van der Salm et al., 2007). Consequently this loss path is limiting the N efficiency.

In the framework of the EU IP project NitroEurope we aim to comprehensively determine the nitrogen flows in a managed grassland system under a cut regime (i.e. no grazing). An operational technique to determine total N-losses in soil cores up to a length of 30 cm using the acetylene inhibition technique was developed. In a recent review by Groffman et al. (2006) the acetylene inhibition technique is considered as a robust technique for soils with a high inorganic nitrogen supply despite its serious limitations. We compare three different approaches to determine N₂ losses (Acetylene inhibition, barometric process separation (Ingwersen et al., 1999), and N₂ soil atmosphere replacement technique (Cardenas et al., 2003)) to characterize the limitation of the acetylene inhibition technique for the Oensingen soil type (Eutri-Stagnic Cambisol).

Based on the measurements with the acetylene inhibition technique the spatial and temporal variability of N₂ losses are addressed.

1.4. Eddy covariance flux measurements of NH₃ with eTR-MS

Sintermann, J., Kuhn, U., Nefel, A., Spirig, C.

Contact: Jörg Sintermann (Jörg.Sintermann@art.admin.ch)

Micrometeorological flux measurements of NH₃ are very difficult due to the stickiness of the NH₃ molecule to all surfaces. Only recently sensitive and fast responding instruments became available that opened the possibility to perform an Eddy Covariance approach to measure NH₃ fluxes.

Norman et al. (2006, 2007) showed that a modified commercial Proton transfer Mass Spectrometer from IONICON using charged oxygen molecules instead of protons reliably measured concentration, but had too strong damping within the drift tube and the inlet lines for EC flux measurements.

In the mean time a new smaller drift tube became available that can be heated up to 180°C. With this configuration the response time was below 1 sec. Heating also the whole inlet line to temperature above 100°C enabled NH₃ EC flux measurements. The performance of the system was tested during two fertilization events (organic manure and urea application) at the Oensingen grassland site in Switzerland. The measured fluxes were in good agreement with an Aerodynamic Gradient approach and showed a similar dynamic range. The sensitivity of the eTR-MS systems seems to be in the same order of magnitude as state of the art gradient systems.

1.5. Ammonia emissions after mulching of grass-clover ley

Brozyna, M.A.

Contact: Michal Brozyna (Michal.Brozyna@agrsci.dk)

Nitrogen availability is one of key limiting elements in organic farming. Its main source for cash crops is fixation of atmospheric N by bacteria which live symbiotically with legumes, which brings a big limitation of the system. Most common practice is to grow a grass-clover ley for one season within a crop rotation and to use legumes as a catch crop. In many systems most of N comes from mulching of above ground biomass of a clover-grass ley (CG). This may lead to unnecessary N losses (ammonia volatilization, denitrification and leaching) and limits N fixation by clover (higher N availability, shadowing, etc). A possible solution to it is to use above ground biomass as a fodder (mixed organic systems) or as a fuel for biogas production and bring nutrients back to the system as animal/post fermentation slurry. In this study we have focused on measuring ammonia emissions after cutting of CG. Two systems were studied: 1) above ground biomass was mulched, or 2) it was taken out from the system. Ammonia volatilization after incorporation of slurries was not measured as there is plenty of literature/data available. To measure ammonia volatilization we have used a set of wind tunnels combined with acid traps (0.02 M boric acid). Conventional wind tunnels were redesigned to limit effects on plants. They are build of a transparent material and are easy to install/remove. Change of

temperature and moisture within the tunnels was not observed. Measurements were conducted within randomized block designed research platform (CROPSYS) in late spring - early autumn of 2009.

1.6. NO-O₃-NO₂ fluxes by gradient, eddy-covariance, and automatic chambers over a bare soil following slurry incorporation

Stella, P., Loubet, B. Laville, P. Fanucci, O., Cellier, P.

Contact: Patrick Stella (patrick.stella@grignon.inra.fr)

Owing to their important role in tropospheric chemistry, NO_x (NO and NO₂) are important gaseous species in the atmosphere. NO_x determine the oxidative capacity of the atmosphere by controlling the ozone production and consumption. The major sources of NO_x in the atmosphere are the combustion of fossil fuel, biomass burning and production from soil microbes.

The poster presents measurements of O₃, NO and NO₂ fluxes over a bare agricultural soil by a gradient system coupled with fast response sensors of NO (Ecophysics, CLD780TR), NO₂ (Luminol, LMA) and O₃ (Sextant LTD, FOS). Additionally, the O₃ fluxes were measured with the eddy-covariance method using a NOAA fast ozone sensor, and the NO and NO₂ emissions were measured with 5 automatic chambers coupled with a 42C ThermoEnvironment Sci instrument.

The experiment took place two weeks following slurry spreading and incorporation. Moreover, due to its geographical localisation (near Paris), the parcel is submitted to anthropogenic pollution from Paris and local advection of NO emitted from traffic lines.

The NO-NO₂-O₃ fluxes measured with the different methods are compared. Specific attention is given to the gradient-flux correction for these chemically reactive species, using information of the correlation between O₃, NO and NO₂ fluctuations to evaluate the effective chemical reaction constants between the three species as a function of height.

Then the kinetics of the NO emissions and the associated O₃ fluxes are then examined, in conjunction with micromet conditions and soil water content.

1.7. Development N₂O and CH₄ fluxes in Danish oak and Norway spruce forests – using chronosequence to study long-term trends

Christiansen, J.R., Gundersen, P.

Contact: Jesper Riis Christiansen (jrc@life.ku.dk)

Afforestation of former agricultural land is a widely used practice across Europe to provide ecosystems services, such as groundwater protection and creating habitats to enhance biodiversity. Furthermore, forests are also able to sequester atmospheric carbon (C) and afforestation can thus be a means to mitigate anthropogenic greenhouse gas (GHG) emissions. However, the net GHG exchange due to land use change also depends on the magnitudes of

fluxes of the strong greenhouse gasses N₂O and CH₄ as well as the development of the forest soil over long time periods.

A recently afforested arable soil will likely contain more available mineral N than older afforested soils. However, dependent on the tree species used in the afforestation process, the input of atmospheric N varies and dense canopies provide larger fluxes of N than more open canopies.

It is thus hypothesised for N₂O 1) that fluxes of N₂O is larger in recently afforested soils compared to soils that have been under forest for a longer time period 2) that the flux of N₂O will not be reduced to the same degree in forests receiving high amounts of atmospheric N as compared to more open forests that receive less atmospheric N.

For CH₄ it is hypothesised 3) that the uptake of CH₄ is less in recently afforested soils compared to soils that have been under forest for a longer time period 4) that the CH₄ uptake of forest soils receiving high amounts of atmospheric N will not increase to the same degree as compared to more open forests that receive less atmospheric N.

To test these hypotheses we measured GHG fluxes on a monthly basis in 16-yr and 39-yr old monoculture oak stands as well as in a 12-yr and 40-yr old monoculture Norway spruce stands for two years.

1.8. N₂O, CH₄ and CO₂ fluxes from a rice paddy field and a mountainous grassland in Spain

Iturrate, M., Carrara, A., Gimeno, C., Sánchez, L., Elisa Bautista, A., Fernández, A., López, R., Ivars, J.F., José Sanz, M.

Contact: Maitane Iturrate (maitane@ceam.es)

Discrete measurements of N₂O, CH₄ and CO₂ were carried out with closed chambers to assess main GHG emissions in two different ecosystems in Spain: a rice paddy field located close to Valencia and a mountain grassland, located in the Pyrenees, which is a NitroEurope-IP level 1 site.

GHG fluxes were measured using manually operated static chambers during the active vegetation period in 2009. For the paddy rice field (Sueca), 6 special chambers with variable height were designed in order to be able to cope with the rice growth. For the grassland site (Alinyà), 8 stainless steel collars (40 cm diameter and 12cm height) were inserted about 8 cm deep in the soil in order to have both a correct sealing of the chambers and to repeat the measurements at the same locations during the whole experiment.

In the rice paddy field, measurements were performed from May to December 2009 with a biweekly periodicity during the active crop period (May - September). In the grassland, measurements were performed every month during the "growing season" (April-October). Two measurements were performed at each sampling day (about 8h and 14h, local time) to assess potential temperature sensitivity of GHG emissions. At grassland site soil CO₂ efflux was also measured by means of an IRGA (EGM-4 SRCI, PP-systems, UK) in the 8 GHG collars and in 40 others collars, in order to validate the GHG measurements and for assessment of spatial variability in fluxes to assess the representativity of the GHG measurements performed with static chambers.

We used a typical protocol for such measurements: for each measurement, samples were taken at 4 different times (0, 30, 60 and 90 min) in 22 ml glass vials to be later analysed by gas chromatography at laboratory. The results are presented here.

1.9. Nitrogen pools and fluxes in the Scots pine stand of Brasschaat

Neiryneck, J.

Contact: Johan Neiryneck (johan.neiryneck@inbo.be)

The Nitro-Europe level I site at Brasschaat is subjected to various N emission sources, both originating from traffic, industrial and agricultural activities. The exchange of reactive N compounds between the forest and the atmosphere, along with its impact on N cycling, has been studied for more than 10 years at a fully equipped measuring tower, located next to a UN-ECE (International Co-operative Programme for the protection of Forests against air pollution - ICP Forest) monitoring plot, featuring *Pinus sylvestris* L. as main tree species.

Study of the N fluxes revealed that ammonia fluxes, determined by the gradient method, dominated the dry deposition flux. The predominance of reduced nitrogen was also reflected in the total dissolved inorganic nitrogen (DIN) inputs collected by throughfall collectors. Throughfall DIN inputs, collected over the period 1992-2008 averaged 34 kg ha⁻¹ yr⁻¹, which consisted for 70% of ammonium. The throughfall fluxes contained also considerable amounts of dissolved organic nitrogen (DON) (5-8.5 kg N ha⁻¹ yr⁻¹). Oxidized and reduced N behaved differently in retention mechanisms. Nitrate losses in the leachate of the forest floor equalled the throughfall NO₃⁻ delivered to the forest floor. On the contrary, about half of the throughfall NH₄⁺ was retained within the forest floor mainly during the growing season. Approximately 60 % of the DIN throughfall fluxes was eventually leached in the seepage water as nitrate.

The N saturation of the forest ecosystem was indicated by the occurrence of NO_x emissions, nitrate leaching and stomatal NH₃ emissions. Despite the high N losses, especially through nitrate leaching, the forest was still accumulating N, especially in the aggrading forest floor. The forest stand itself, was found to be a poor N sink.

Total C accumulation in the biomass and LFH-layer was 1.5 Mg C ha⁻¹ yr⁻¹. Hence, per unit N deposited into the ecosystem, about 30-35 g of C were being sequestered.

1.10. Intercomparison of methods to assess ammonia and ammonium concentrations in ambient air – results of a field experiment performed in Braunschweig, Germany, 2005 to 2008

Dämmgen, U., Thöni, L., Lumpp, R., Gilke, K., Seidler E., Bullinger, M.

Contact: Ulrich Daemmgen (ulrich.daemmgen@daemmgen.de)

In 2005, the Commission on Air Pollution Prevention (KRdL) of VDI (Association of German Engineers) and DIN (German Institute for Standardization), responsible for the development of

technical guidelines for measurements within the field of air quality, initiated measurements of ammonia concentrations in ambient air in order to establish the relevant guidelines. In this context laboratory and field experiments were performed to establish recommended procedures and describe the characteristics of standardized measuring procedures. Intercomparison measurements at the FAL experimental site in Braunschweig, Germany, started in March 2005 and ended in December 2008, comprising parallel sampling with cylindrical and annular denuders as well as circular and tubular passive samplers operated by three institutions from Germany and Switzerland.

For ammonia, denuder systems could be calibrated in laboratory experiments. In the field experiment, denuders proved to be reliable and accurate enough to allow for statements with regard to threshold limit values. Experiments with passive samplers proved that they can be operated with adequate accuracy. However, passive sampling requires regular calibration with denuders.

The presentation will report experimental details and results, the conclusions drawn and the recommendations made for practical monitoring as expressed in the new guidelines VDI 3869 sheet 3 "Measurement of ammonia in ambient air. Sampling with diffusion separators (denuders). Photometric or ion chromatographic analysis" and VDI 3869 sheet 4 "Measurement of ammonia in ambient air. Sampling with passive samplers. Photometric or ion chromatographic analysis".

1.11. The effect of water vapour on N₂O analysis by QC laser spectroscopy for micrometeorological flux measurements.

Emmenegger, L., Tuzson, B., Zeyer, K., Nefel, A.

Contact: Lukas Emmenegger (Lukas.Emmenegger@empa.ch)

A novel Quantum Cascade Laser Absorption Spectrometer (QCLAS) was tested to monitor N₂O exchange fluxes over intensively managed grassland using the eddy covariance approach. The instrument employs a continuous wave quantum cascade laser to scan over the absorption features of N₂O, CH₄ and water vapor at 7.8 μm. The precision of the N₂O flux measurements was determined to 0.2 nmol m⁻² s⁻¹ but the accuracy can easily be affected by water vapour interferences twice as large. These water vapour interferences are not only due to the respective gas dilution effect but also to an additional cross sensitivity of the N₂O analyzer to water vapour (0.3 ppb N₂O / % H₂O). Both effects cause a negative bias of similar magnitude (0.3 nmol m⁻² s⁻¹ N₂O flux / mmol m⁻² s⁻¹ H₂O flux) in the flux measurements. While the dilution (or density) correction is a well known and routinely applied procedure, the magnitude of the analyzer cross talk was unexpected and may not be limited to this wavelength or spectroscopic setup. Several mechanisms can be invoked to explain the empirically determined cross sensitivity, but the most likely source are changes in the pressure induced broadening of the absorption features due to variations in water vapour mixing ratios.

This pressure broadening is caused by the perturbation of the energy levels due to molecular collisions and it is normally not taken into account in current data retrieval algorithms. Theoretical estimates and experimental work will be presented to further support and quantify this effect. Our findings suggest that measurements of small "background" N₂O fluxes should

only be done after careful evaluation of the instrumental response to water vapour or on dry samples.

1.12. Assessment of the nitrogen and carbon budget of a Dutch coniferous forest, Speulderbos

Frumau, K.F.A., Bleeker, A., Hensen, A., Erisman, J.W., van der Tol, C., Duijzer, J., Weststrate, H., van Pul, A., Stolk, A

Contact: Arnoud Frumau (frumau@ecn.nl)

Within the framework of the NitroEurope project measurements of the major components of the N budgets as well as C budget have been taken up at the Douglas fir site Speulderbos. These measurements were performed previously during several projects in the nineties, with the forest left unaffected but growing swift ever since.

The current C and N budget is compiled from measurements for major components and a comparison with historic results is made. The total C budget of the forest is derived from eddy covariance measurements of the CO₂ exchange. The N budget of the forest is more complex, it includes gaseous exchange in many different forms (among others, NO, NO₂, N₂O, NH₃), as well as input by rain and leaching of N-compounds with the soil water.

1.13. Nitrous oxide flux and soil profile N₂O concentration in response to irrigation, nitrogen inputs and temperature in riparian grassland plots in NE England.

McAuley, L., Reay, D., Smith, P., Heal, K.

Contact: Lena McAuley (lena.mcauley@ed.ac.uk)

Diffuse nitrate (NO₃⁻) pollution is a major problem affecting riverine and coastal waters across the world. High NO₃⁻ loadings can cause eutrophication and incur substantial economic costs to water companies aiming to comply with drinking water nitrate limits. Within Europe, diffuse NO₃⁻ pollution is being addressed through several directives aimed at improving water quality, in particular the EC Nitrates Directive and the wider Water Framework Directive. The implementation of the Nitrates Directive requires the designation of Nitrate Vulnerable Zones (NVZs) within which farmers must adhere to codes of good farming practice controlling fertilizer/manure applications. It also promotes the implementation of riparian buffer strips, to intercept and reduce diffuse pollution. Microbially-mediated denitrification is the key process utilised in such buffer strips to reduce NO₃⁻ through a series of intermediate products to produce nitrogen gas (N₂). Incomplete denitrification has the potential to release the potent greenhouse gas nitrous oxide (N₂O), thereby swapping a water pollution issue for a climate change problem. Here we investigate the extent to which such nitrogen pollution swapping occurs in a paired-plot, grassed riparian zone on a farm in northeast England over a 2-year period. We examine the effects of irrigation, temperature and N addition on *in situ* soil profile N₂O concentrations and

net fluxes as well as in triplicate soil cores; 21cm by 40cm, incubated under controlled conditions. Data from the field show that, even with relatively high irrigation rates and nitrate loadings, net fluxes remain low. However within the soil profile N₂O concentrations may exceed 6ppm. Similarly, soil core incubation data showed that below surface (30-40cm depth) N₂O concentrations can be very high (~420ppm) even where net fluxes remain low (~1ppm m⁻² h⁻¹), suggesting that much of the N₂O produced at depth is denitrified before it reaches the soil surface.

1.14. A comprehensive approach to soil-atmosphere trace gas flux estimation with static chambers

Pedersen, A.R., Petersen, S.O., Schelde, K.

Contact: Asger R. Pedersen (AsgerR.Pedersen@agrsci.dk)

The frequent need for non-linear models to estimate soil-atmosphere trace gas fluxes with static chambers has been recognized for decades (Hutchinson and Mosier, 1981; SSSAJ 45: 311-316), but in practice a number of issues remain:

- Several non-linear models and approaches have been suggested in the literature, and thus a specific choice has to be made.
- Molecular diffusion theory predicts non-linear concentration data, but in practice linear data are often encountered, and in such cases non-linear models will be overparameterised and can not be fitted.
- When non-linear models are applied to noisy concentration data from sites with little or no gas flux, they often, erroneously, estimate a huge flux, so algorithms are needed to detect and treat such cases appropriately.

We present a comprehensive approach based on a specific application of the non-linear model proposed by Hutchinson & Mosier (1981). Our approach provides a safe and transparent way to fit non-linear data sets when appropriate, and includes procedures for automatic detection and analysis of linear data sets and data sets representing no significant flux.

This new procedure has been implemented in a R package called HMR (<http://www.r-project.org>). Both R and R packages are free software. By a single R command, the HMR package reads static chamber data from a standard semicolon-separated data file, analyses data automatically, requests the user to confirm or change the recommended data analysis for each data series based on a graphic interface, and finally outputs the results to a semicolon-separated data file. Semicolon-separated files can for instance be managed by spreadsheet software or text editors. Examples of model application to field data are presented.

2. Impacts of changes in external drivers (global change, N deposition, management, land use change etc.) on fluxes and exchange of N, C and GHG in terrestrial ecosystems

2.1. Impact of land use on stream C and N export in the Danish landscape of Bjerringbro

Wohlfart, T., Breuer, L., Exbrayat, J., Schelde, K.

Contact: Teresa Wohlfart (teresa.wohlfart@umwelt.uni-giessen.de)

The Danish economy is highly dependent on agriculture which led to an immense agricultural intensification over the last decades. It is assumed that this development has a large influence on the environment. The NEU-C4-common field experiment was held in the Danish landscape of Bjerringbro in April 2009 to study the impact of intensive agriculture on the nitrogen cycle in air, soil and water.

Two streams run through the investigation area (368,3 ha) and converge to the Tyrebaekken stream. During the campaign pig slurry was applied to two fields within the catchment. Snapshot samplings were taken from defined in-stream points ($n = 21$) and drains ($n = 11$), and were analysed for NH_4^+ , NO_3^- , TN, TOC, DOC, EC and pH. Nested discharge measurements were performed to calculate area specific loads.

To check the effect of slurry application, water samples were taken in vicinity to the respective fields. We found no difference in NO_3^- concentrations up- and downstream, but higher concentrations in the drains.

Two further sampling periods were arranged in August and September 2009 to investigate the impact of land use on stream chemistry. We found significant differences for NO_3^- between the two stream sections during the three sampling periods. The northern part always showed higher concentrations than the southern part. Furthermore we found a decreasing trend in concentration from source to convergence for both streams. The seasonal trend shows a lower NO_3^- concentration in summer for the southern stream, the northern stream revealed stable concentrations. Ammonia remained mostly under the detection limit. pH showed consistent values through the time for both streams. EC always indicated higher values for the southern stream. TN, TOC, DOC are still to be analysed, but first results from April showed lower concentrations for the northern stream. We'll finally correlate land use and nutrient fluxes in stream to assess the influence of agriculture on water quality.

2.2. Soil chamber and eddy covariance measurements of CO_2 , CH_4 and N_2O exchange in a deciduous oak woodland in south east England

Yamulki, S., Wilkinson, M., Morison, J.I.L

Contact: Sirwan Yamulki (sirwan.yamulki@forestry.gsi.gov.uk)

There is a demand for reliable and long term simultaneous measurements of the main

greenhouse gas (N_2O , CH_4 and CO_2) fluxes to assess the total greenhouse (GHG) budget of forestry and the effects of forest management. Data is also needed for input into simulation models and for model verification and up-scaling under a range of climatic conditions.

The aim of this research was therefore to quantify the annual and seasonal GHG fluxes of CO_2 , CH_4 and N_2O from a commercial managed oak woodland. The specific aims were to i) measure trace gas exchange from forest floor (i.e. 'soil' emissions and uptake from litter, roots and soil microbial activity), by soil enclosures and at the forest stand scale by eddy covariance; ii) investigate the effect of environmental variables (soil and atmospheric) including N-deposition on fluxes; iii) quantify total GHG budget and C stocks based on data measurement and modelling; iv) and to assess the effect of the disturbance to soil and vegetation during a normal tree thinning operation.

The experiment is located within the Straits Enclosure (Surrey, UK), in a mature oak forest (*Q. robur*) interspersed with approximately 10% ash (*Fraxinus excelsior*) with an understorey dominated by hazel (*Corylus avellana*) and hawthorn (*Crataegus monogyna*). The soil is a surface-water gley with a depth of 80 cm to the C horizon of the cretaceous clay with a pH of 4.6 and 4.8 in the organic and mineral horizons respectively.

Complementary data of soil solution chemistry, N deposition and climatic conditions were obtained from an adjacent long term Environmental Change Network plot. The results obtained by soil enclosures (since september 07) and by eddy covariance (since July 09) will be explained in term of the total global warming potential, seasonal flux patterns and relationship with the key environmental parameters.

2.3. Does a land use change influence N dynamics and N_2O fluxes on degraded fen peatland?

Juszczak R., Serba T., Augustin J., Sommer M., Giebels M., Chojnicki B., Minke M., Bayer M., Behrendt A., Olejnik J.

Contact: Radoslaw Juszczak (radjusz@up.poznan.pl)

Fen peatlands in Germany and North East Europe play an important role in a global greenhouse gas (GHG) balance, as they store big amount of carbon and nitrogen. Unfortunately, even 95% of fen peatlands existing in Germany have been drained and degraded and due to this reason they are a strong CO_2 and N_2O sources. Therefore, this is essential to investigate the effect of different land use strategies on GHG balances as well as C and N dynamics in soil to know whether is possible to reduce GHG emission to the atmosphere by changing a land use type and in which extend this will help to counteract a global warming.

The aim of our study is to assess the influence of land use change onto N_2O fluxes and N dynamics in soil on agriculturally used fen peatland. The manipulation experiment was established at the end of 2006 in Paulienenaue (west from Berlin, in Brandenburg province, Germany) and consists of three experimental plots: 1) arable (control); 2) arable converted to extensive meadow (new grassland) and 3) pasture converted to extensive meadow (old grassland). The soil nitrogen dynamics (net and gross mineralisation, immobilisation, nitrification and nitrate consumption rates) were investigated using ^{15}N isotopic dilution technique. Additionally the N_2O fluxes were measured every 2-3 weeks by static chamber

technique.

Results of our study clearly indicate that the conversion of arable land into grassland leads to a strong reduction of N₂O fluxes. The fluxes of N₂O on pasture converted to extensive meadow (old grassland) are slightly bigger than on the newly established grassland (even if management on both subsites is the same). Thus, it can be concluded that conversion of arable lands located on degraded fen peatlands onto grassland can lead to essential reduction of N₂O fluxes. However, this effect requires much more long term investigations to know how long this effect can occur.

2.4. C sequestration in intensively managed grasslands is expensive

Conen, F., Neftel, A.

Contact: Franz Conen (frans.conen@unibas.ch)

Conversion of ploughed land into permanent grassland is considered one option to work against the current increase in atmospheric CO₂ (Soussana et al., 2004). There are a number of reasons to support the establishment of permanent grasslands, including them being habitats of diverse and endangered plants, insects and birds with an intrinsic value outside the economic domain. In contrast, the function as a carbon sink is not an essential value nor is it specific to grasslands. Thus, an economical consideration is indicated.

Frequently, soils under the plough have lower soil organic matter contents than soils under permanent grassland. In intensively managed systems, however, fertilisation and a high crop productivity result in increased soil organic matter contents even under arable crops. Here, carbon sequestration through a conversion to permanent grassland can only be achieved when additional nitrogen is added. Otherwise increased mineralisation of the accumulated soil organic matter may even lead to carbon losses (Ammann et al., 2009). Organic matter in intensively managed soils usually has a C:N ratio around 10. Hence, the sequestration of 1.00 Mg of C in form of organic matter is at the same time a sequestration of 0.10 Mg of N. In intensively managed systems this N has to be added in form of mineral fertiliser. About 25% of applied mineral N fertiliser is lost to the atmosphere and 20% are lost to aquatic systems (Smil, 1999). To provide 0.10 Mg N for sequestering 1.00 Mg C, one needs to add about 0.18 Mg fertiliser N. If added in form of ammonium nitrate at 200 € per ton with an N content of 28%, related costs are 129 €. If added in form of urea at 260 € per ton and 46% N content, the costs are 102 €. During the past few years prices for one ton of CO₂ in carbon trading were up to 30 €. A decline during the recent economic downturn has led to prices currently below 15 €, equivalent to 55 € per ton of C. Converting intensively managed crop rotations to permanent grassland would be an expensive form of carbon sequestration. It also leads to a type of grassland with little diversity. Consequently, we may abandon the aspect of carbon sequestration when thinking about the future of intensively managed agroecosystems and be guided by more relevant issues.

2.5. Effects of legume density and stocking rate on N₂O emissions of an upland pasture

Klumpp, K., Bloor, J.M.G., Ambus, P. Tallec, T., Soussana, J.F.

Contact: Katja Klumpp (kklump@clermont.inra.fr)

Understanding the impacts of land-use change on N₂O emissions is essential for accurate predictions of ecosystem responses to global change. Whilst the various pathways for N₂O cycling in soils are relatively well described, the role of plant diversity and other N sources (legumes) on N₂O emission remains unclear. We used a grassland grazing experiment to investigate N₂O fluxes in response to animal stocking rate and legume density over two growing seasons. Our objectives were to i) determine direct and indirect effects of plant community structure (via stocking rate, high vs low) on N₂O fluxes, and ii) assess the contribution of other N sources such as high legume presence on N₂O fluxes. The study was carried out at semi-natural permanent grassland site subject to continuous grazing from May to October. Two adjacent paddocks were managed with either a mean stocking rate of 1.2 LU ha⁻¹ yr⁻¹ and an N fertilisation of 260 kg N ha⁻¹ yr⁻¹ (intensive treatment) or a mean stocking rate of 0.5 LU ha⁻¹ yr⁻¹ (extensive treatment). In April 2008, eight automatic chambers were installed in the intensive treatment on sites with different %presence (0-25%) of legumes. N₂O fluxes were measured at 4h intervals using infra red gas analyser, and chamber positions were moved monthly. N₂O emissions were measured continuously from April to December and 15N₂O was analysed twice over 8 weeks following the application of 15N labelled fertiliser. During this period, grazing was simulated by cuts: at each cut, biomass was sorted into functional groups (grass, forbs and legumes) and soil cores were taken to determine 15N of shoot and roots and mineral N in soil (NH₄/NO₃). In a second study (2009), four chambers were set up in each of the extensive and intensively grazed paddocks and urine was applied monthly throughout the growing season to a subset of the chambers. Analyses for 2008 show a strong seasonal variation of N₂O efflux due to changes in water filled pore space (WFPS).

2.6. The greenhouse gas budget of an intensively managed cropping system in the Mediterranean climate

Bertolini, T., Di Tommasi, P., Ranucci, S., Ottaiano, L., Oliva, M., Vitale, L., Magliulo, V., Fierro.

Contact: Teresa Bertolini (teresa.bertolini@gmail.com)

The agricultural sector contribute significantly to greenhouse gas (GHG) emissions via product and machinery manufacture, transport of materials and direct and indirect soil greenhouse gas emissions. Changes in management and in the climatic factors can affect the agriculture contributions to GHG emission.

A field study was started in 2007 to determine the impact of intensive management, the

biological, chemical and physical variables on GHG emissions and on the crop production. The main summer crop was maize while the winter crops were ryegrass and fennel. N management was that a typical of the area, an intensive alluvial plan in Southern Italy. Data are reported on GHG emissions throughout 2 years as a function of crop management and environmental factors.

2.7. Seasonal dynamics of dissolved CH₄ in stream water – contribution to the annual C budget on a northern fen

Lohila A., Aurela M., Hatakka J., Kuitunen E., Tuovinen J-P., Laurila T.

Contact: Annalea Lohila (annalea.lohila@fmi.fi)

In addition to the carbon dioxide (CO₂) exchange, the carbon (C) balance of mires is determined by the methane (CH₄) emission and the amount of C transported away with the surface waters. However, a significant amount of C may be leached out from a wetland not only in particulate, but also in dissolved form, especially in spring during the snow melt. Since March 2009, we have measured the concentration of dissolved CH₄ in the stream draining the Lompolojänkki sedge fen in northern Finland (68.0°N, 24.1°E). The CH₄ concentration in the peat water has also been monitored on a daily basis. A measuring weir was installed at the site in 2008 to measure the discharge rate of stream water. Based on the CH₄ concentration in water and the discharge rate, the annual loss of CH₄ in dissolved form was calculated. In this presentation we will show the annual dynamics of the dissolved CH₄ in stream water, study the factors controlling the concentration variation, and compare the amount of dissolved CH₄ to the soil-atmosphere exchange of CH₄, both contributing to the C loss from the fen. Finally, we aim at the first estimate of the full C balance of the fen.

2.8. Production and emission of N₂O from a drained and afforested peat soil

Thomsen, F., Rütting, T., Klemetsson, L.

Contact: Frida Thomsen (frida.thomsen@dps.gu.se)

The production of nitrous oxide (N₂O) was studied in year-round experiment in drained and afforested peat soils. Drained organic soils are considered an important source for atmospheric N₂O accounting for 15% of the total N₂O emission from Swedish forests. For the study, the NitroEurope IP experimental forest site Skogaryd, located in South-western Sweden, was selected. The forest is part of a former fen, which was drained in the 1870's and used as an agricultural land before forested in the 1950's. To investigate the emission of N₂O from the soil and to evaluate the role of the rhizosphere and the mycorrhiza, chamber incubation experiments were established. To exclude fine roots the soil was trenched at three plots at the site. At each plot the soil was trenched and a PVC frame was inserted to a depth of 0.6 m. The frames were equipped with fabric that had a mesh size of 50 µm or 1 µm. The frames with mesh size 50 µm,

allows mycorrhiza in-growth but not the fine roots, while the ones with mesh size 1 μm allow no in-growth. For soil emissions, six flux chambers (two replicates for the treatments and two controls) were placed at three different plots within the forest. For collecting samples from deeper soil layers (5 to 60 cm) gas probes were installed below the control flux chambers. From the flux chambers gas samples were collected at fixed intervals of 4, 8, 16 and 32 minutes after closure of the flux chambers. All samples were analysed by gas chromatography. Besides determination of the N_2O concentrations, additional soil samples were taken for DEA analysis. In our presentation a detailed overview on the methods will be given and the results of the period 2006 to 2008 will be presented.

3. Plot scale modelling of processes controlling the bio-sphere-atmosphere exchange of trace gases to predict effects of changes in climate, land use and land management on gas exchange of C and N compounds

3.1. Methane production and consumption in upland forest soil layers determined from concentration profiles and chamber fluxes

Pumpanen, J., Pihlatie, M., Kieloaho, A.

Contact: Jukka Pumpanen (jukka.pumpanen@helsinki.fi)

Methane (CH₄) emissions and uptake are usually measured with static chambers, and recently also with eddy covariance technique. These methods do not provide with information on the processes underlying CH₄ consumption and production in the soil such as the vertical distribution of methanotrophic activity in the soil. The soil gradient method, the calculation of gas fluxes based on concentration differences between the soil layers or between the top-soil layer and the atmosphere, has recently become increasingly popular in studying CO₂, N₂O and other greenhouse gas emissions.

We developed a profile-based approach to quantify the consumption and production of CH₄ in different soil layers in situ. The model is based on the CO₂ and N₂O diffusion model by Pumpanen et al. (2008) and Pihlatie et al. (2007) into which methane oxidation and production processes were added in each soil layer (organic, eluvial and illuvial layers and parent material). The modelled CH₄ fluxes from the soil surface were compared to the fluxes measured with conventional static chamber technique. The preliminary results show that laboratory based CH₄ oxidation rates in each soil layer may be too high compared to oxidation rates estimated based on the in situ gradient method. This might be due to disturbance of soil upon sampling and incubation that results in higher oxygen concentrations in the soil compared to intact soil.

3.2. Temporal dynamics of N₂O emissions on compacted or not compacted sugar beet fields: measurement and modelling

Bessou, C., Mary, B., Leonard, J., Rousel, M., Grehan, E., Gabriele, B.

Contact: Joel Leonard (joel.leonardl@laon.inra.fr)

N₂O emissions from cropped areas largely contribute to global warming. Although numerous studies have focused on the measurement, on the analysis of contributing processes and on the modelling of N₂O emissions, the lack of suitable methods for continuous measurement of emissions have oriented most of the work toward explaining peak emissions following fertilisation. Since then, automatic chambers have been developed that allow to follow the complete dynamics of emissions over long periods of time. We have built a set of 6 automatic chambers and used them to measure N₂O emission dynamics during two sugar beet crop cycles (2007 and 2008), on an uncompacted (3 chambers) and a compacted (3 chambers) situation. Results have shown that both the amplitude and temporal dynamics of emissions are affected by compaction. In the first part of the crop cycle, the dynamics of emissions was close to what was expected, with larger emissions on the compacted situations and at the beginning of the crop cycle, as a consequence of higher WFPS on the compacted soil and active nitrification and denitrification of widely available NH₄ and NO₃ substrates. After mid summer, the dynamics of emissions was characterized by periods of higher emission on the compacted situations and isolated and very marked peaks on the uncompacted situations, which contributed significantly to total emissions. Although we were able to simulate the main features of N₂O emission before summer using an improved version of the NOE model, we failed at reproducing the subsequent emission patterns. Several hypothesis were proposed to explain the observed pattern of emission in late summer: i) possible unconsidered substrate inputs ; ii) possible increased N₂O/N-denitrified ratio ; iii) possible punctual increase in nitrate availability. Numerical experiments however showed that none of these hypotheses alone was able to explain such high emissions and that only a combination of them could result in large emissions.

3.3. Simulating soil N₂O and CO₂ emissions from arable organic and conventional systems using two biogeochemical models

Chirinda, N., Kracher, D., Lægdsmand, M., Porter, J., Olesen, J.E., Petersen, B., Kiese, R., Butterbach-Bahl, K.

Contact: Ngonidzashe Chirinda (Ngonidzashe.Chirinda@agrsci.dk)

Modelling of soil nitrous oxide (N₂O) and carbon dioxide (CO₂) emissions is challenging due to complex interactions of soil physical and biochemical properties that influence the production and transport of these gases. The objective of this study was to simulate soil N₂O and CO₂ emissions from three different organic and one conventional cropping system using two different process-oriented, biogeochemical models. The simulations from the two models were validated against multiple field measurements made in winter wheat plots from four different cropping systems within a long-term experiment in Denmark. For this study, we used the Modular Biosphere SimuLation Environment (MoBiLE) framework and the Farm ASSEssment Tool (FASSET). In the MoBiLE framework, different sub-modules were used for simulation of ecosystem carbon and nitrogen turnover and biosphere-atmosphere exchange. Despite other discrepancies, these two models use different algorithms to simulate soil N₂O production: MoBiLE-DNDC uses the “anaerobic balloon” concept, while FASSET makes use of semi-empirical functions. Winter wheat growth parameters were slightly modified in MoBiLE-DNDC. No calibration of the FASSET model was performed. MoBiLE-DNDC showed several

limitations in accurately predicting daily soil N₂O and CO₂ emissions. Nevertheless, annual cumulative N₂O (1.1–1.3 kg N₂O-N ha⁻¹) and CO₂ (2891–3543 kg CO₂-C ha⁻¹) emissions from MoBiLE-DNDC were similar to those estimated from field measurements which, respectively, ranged between 0.6–0.9 kg N₂O-N ha⁻¹ and 3173–4578 kg CO₂-C ha⁻¹. The FASSET model satisfactorily simulated daily soil CO₂ emissions but also showed limitations in modelling daily soil N₂O emissions. Simulated annual soil CO₂ and N₂O emissions, from the FASSET model, that correspondingly ranged between 3454–5356 kg CO₂-C ha⁻¹ and 1.1–7.0 kg N₂O-N ha⁻¹, were both higher than annual emissions estimated from field measurements.

3.4. Improving N₂O simulation with the Pasture Simulation Model (PaSim)

Graux, A., Lardy, R, Soussana, J.

Contact: Anne-Isabelle Graux (aigraux@clermont.inra.fr)

PaSim is a biogeochemical model that simulates fluxes of C, N, water and energy in managed grasslands, either cut or grazed. Vegetation is represented at the community scale with grasses and legumes. The soil module of PaSim is decomposed in 5 SOM pools, so that it makes difficult to initialize PaSim with measurements. Therefore the model is usually set to equilibrium.

This model is being used intensively in a set of European research projects aiming at understanding the C and N cycles, C sequestration, GHG and the effects of climate. Nevertheless PaSim tends to over-estimate the background N₂O fluxes and fails to faithfully reproduce timing, duration and magnitude of peak emissions triggered by the application of mineral and organic fertilizers and by rain events.

In order to perform N₂O emission, some developments have been done: i) adding a legume dynamics; the legume fraction is calculated by assuming that the C:N substrate ratio determines the equilibrium between fixing and non fixing atmospheric N₂ species, ii) as we know that soil pools are rarely at equilibrium, we have developed a matrix inversion method allowing to estimate initial SOM pools values, by fitting simulated and observed Respiration of the ecosystem (Reco) and Gross Primary Production.

To assess these improvements, we compared observed vs. simulated N₂O emissions for the sites of the CarboEurope IP Project. Results showed that i) adding a legume dynamics enhances biological N₂ fixation and increases N₂O cumulated emissions, underlying the importance of the functional role of biodiversity in modelling GHG; ii) when Reco is fitted to observed values, SOM is reduced vs. equilibrium, really improving N₂O emissions, but unfortunately the fitted SOM values are actually unrealistic. Combining both improvements give more or less accurate N₂O emissions simulation according to sites. Optimization of nitrification and denitrification parameters is also planned and should allow more realistic simulations.

3.5. Simulation of nitrous oxide peak emissions from grassland on drained peat soils

Stolk, P.C, Hendriks, R.F.A., Jacobs, C.M.J, Moors, E.J

Contact: Petra Stolk (petra.stolk@wur.nl)

Nitrous oxide (N_2O) is a very strong greenhouse gas, with agricultural soils as its main anthropogenic source. Peat soils with agricultural land use cause large emissions, due to abundant available organic matter and moist conditions. Various management practices, like fertilization or tillage, can give rise to pulses of N_2O emissions. In spite of their short duration, in the order of a couple of days to weeks, these pulses can constitute a major part of total annual N_2O emission. Understanding, predicting and ultimately mitigating these pulses poses a considerable challenge. Process based models are an indispensable tool to look at the biogeochemical system in more detail than we possibly can with measurements. In this study the model combination SWAP-ANIMO is used to assess the sources of N_2O peak emissions in Dutch drained peat soils.

We simulated soil moisture, soil temperature and N_2O fluxes for three sites in The Netherlands. The results show that the simulation of highly dynamic N_2O fluxes is possible, but requires accurate modelling of the hydrology, the carbon cycle and the nitrogen cycle. Failure in the simulation of peak emissions can be traced back to failures in the simulation of soil moisture content. In peat soils, macropores are important in the simulation of soil moisture, especially after dry periods. Peak emissions from peat land are the result of coupled nitrification-denitrification. Nitrification produces continuously nitrate, which is the substrate for peak emission of N_2O produced by denitrification. Only after ammonium fertilization nitrification contributes directly to the peak emissions. The larger peaks occur just after soil saturation, when the groundwater level is decreasing. N_2O production then takes place just above the groundwater level.

4. Up-scaling from plot to regional scales – analysing interactions on different spatial scales

4.1. Ammonia, N₂O and CO₂ concentration and flux measurements on an agricultural landscape near Bjerringbro, Denmark

Braban, C.F., Famulari, D., Riddick, S., Dragosits, U., Theobald, M., Schelde, K.

Contact: Christine Braban (chri2@ceh.ac.uk)

The NitroEurope IP common field experiment aimed to simultaneously measure targeted flows of reactive nitrogen (Nr) through the soil, atmosphere and water courses of a landscape. This experiment provides a series of ‘snapshots’ (spatial distributions at a specific time) of the principal Nr compounds within the landscape over a period of two weeks

A static sampling assembly to measure the agricultural plume and the micrometeorology. The chemical species studied concurrently were: N₂O, ammonia, H₂O and CO₂. A footprint analysis and Gaussian plume modelling will be applied to assess emission strengths of point and area of sources determined by wind direction and atmospheric conditions.

For the N₂O data series, preliminary flux data seem to be not very far from zero, with perhaps 1 day being slightly different (23rd April). A strong ammonia plume was observed post-slurry application. An analysis of the N₂O, H₂O and CO₂ fluxes and the ammonia gradient will be analysed to interpret the emissions following the slurry application and the results will be discussed in the context of the landscape which consisted of a high ammonia background due to the intensive fertilising activity of the measurement period and the meteorological conditions which were warm and dry.

4.2. Matter fluxes between atmosphere and an agricultural surface – Modified Bowen Ratio (MBR) versus Eddy Covariance (EC) Measurements

Brust, K., Hehn, M., Bernhofer, C.

Contact: Kristina Brust (kristina.brust@tu-dresden.de)

Changes in climate and land use interact in a complex system with various feedbacks influencing water, N, and C fluxes. An objective within the project EcoTech is the detection and validation of climate and land use effects on these fluxes and their contribution to the matter budgets. One of the focal points is a long-term observation site within the European carbon projects.

In 2009, simultaneous measurements of CO₂ / H₂O and NO_x / (NH₃ indirect) were performed over a field of winter barley at Klingenberger Agrarstation (KLAS) in Saxony (Germany). A MBR system was installed parallel to an already existing EC tower for measurements of the N species and to account for the larger response time of analyzers measuring N-components.

Within the MBR a single Infrared Gas Analyzer ($\text{CO}_2 / \text{H}_2\text{O}$) and two Chemiluminescence Analyzers ($\text{NO}_x / \text{NH}_3$) are employed to detect the concentrations / gradients of interest.

Based on the first dataset, intercomparisons are carried out between both measurement systems in terms of turbulent energy and matter fluxes. The MBR tends to produce higher estimates of sensible heat (H) and latent heat (LE) fluxes, but with close correlation to the EC-system. The CO_2 flux exhibits more scatter by comparison. Additionally the different behavior of fluxes during complete plant cover (winter barley before harvest) and bare soil (after fertilization and seeding of rapeseed) are pointed out.

This long-term measurement campaign continues at least until August 2010, so it will cover the complete growth period of rapeseed.

4.3. Temporal and small scale spatial variability of chamber measured N and C trace gas fluxes following slurry application

Butterbach-Bahl, K., Willibald, G., Cellier, P., Durand, B., Bienkowski, J., Janku, K., Bertolini, T., Sanz, A., Dalgaard, T., Schelde, K., Theobald, M.

Contact: Klaus Butterbach-Bahl (klaus.butterbach-bahl@kit.edu)

In the framework of a landscape experiment near Bjerringbro, Denmark, in April 2009, we studied the effect of slurry application to an arable field on temporal and small-scale spatial variability of N- and C-trace gas fluxes by use of static automated and manual chambers. Slurry application resulted in a significant increase of N_2O and NO emissions by a factor of 2-10. Spatial variability of fluxes also increased following slurry application. Moreover, slurry application and diurnal variations in temperatures resulted in a pronounced diurnal variation in N trace gas emissions, which could not be detected before. Peak N_2O emissions did not occur on the day following application, but was delayed by approx. 4 days. In contrast to N_2O , soil NO emissions responded immediately to slurry application, while flux rates only slightly increased further over the observation period of 10 days. Since the general meteorological conditions were stable and rainfall did not occur, the temporal delay of N_2O emissions as compared to NO emissions is a clear indication that the microbial population needed a few days to adapt to conditions of surplus substrate supply and that production processes for N trace gases may have shifted from predominantly nitrification to predominantly denitrification dominated.

CH_4 uptake was marginal and slurry application further reduced uptake dynamics and sporadic net emissions of CH_4 from the slurry were observed for some chambers. This is in-line with expectations, since CH_4 uptake by arable systems is known to be low and can easily be affected by fertilization.

4.4. Investigating N₂O emissions variability at landscape scale: results from the Bjerringbro experiment

Cellier, P., Durand, B., Decuq, C., Bienkowski, J., Janku, K., Bertolini, T., Sanz, A., Schelde, K., Theobald, M.

Contact: Pierre Cellier (cellier@grignon.inra.fr)

N₂O emission are variable at landscape scale due to the variability in land use, crops, agricultural practices as well as natural factors such as soils conditions and topography. An experiment was designed to investigate the main sources of variations in a typical mixed farming landscape near Bjerringbro, Denmark, in April 2009. This landscape was characterized by sandy soils (>70% sand on all sites) and dry climatic conditions during the experimental period. Land use was mainly wheat fields and grassland, with application of pig or cattle slurry over wheat at this period of the year. The measurements were made with a set of 5 or 6 static chambers per field. We investigated (1) the land use (wheat field, grassland, wetland), the topography (measurements along a transect from the plateau to the stream), (3) fertilisation events (pig slurry application) and (4) rainfall. N₂O concentration was sampled in vials under pressure and analysed in the lab using a gas chromatograph.

The N₂O emissions were relatively low, with an average of 5.2 ng/m²/s and a range from 0.2 to 20 ng/m²/s (averages over 5 or 6 chambers). Most sites were small sinks for CH₄. The first driver of N₂O emissions were the slurry application, with observed twofold increase in emission. The second driver was rainfall: an addition of 12 mm water increased significantly the emission. However, in both cases, the increase lasted not more than several days. Surprisingly, it was not possible to see any effect of the position on the topography. Even in a wetland and a grazed grassland near the stream, with large water content (40-190 g water/g dry soil), the emissions were lower than in the nearby fertilized wheat fields. Similarly, emissions in the grassland were low, despite large bulk density (1.45 in the top 10 cm). These results are interpreted in the context of a very dry period, which was not favourable to N₂O emissions by denitrification, nor by a control of emissions by natural drivers.

4.5. Towards Resilient Agro-Ecosystems Designed for N and C Management

Christen, B., Dalgaard, T.

Contact: Benjamin Christen (Benjamin.Christen@agrsci.dk)

Using the NitroEurope IP study landscape at Bjerringbro, Denmark as setting, this poster shows possible scenarios for the development of climate change resilient agro-ecosystems. Climate change is treated as inevitable in the design process and the focus is therefore on the resilience of the developed land-management system. Agroforestry practices adapted to intensive agriculture are proposed as promising measures to design future agricultural landscapes. The 'green growth' initiative by the Danish government is examined as a possible tool in facilitating reductions in nitrates and ammonia losses from arable land or pastures by exploiting the nutrient removal potential of biomass production in buffer strips and shelterbelts. Enhanced carbon

sequestration, phosphorous retention and reductions in nitrous oxide greenhouse gas emissions are examined as additional benefits.

Design:

- Overview of the proposed land-management designs and their possible effect on N cycling
- Examination of additional benefits
- Map of NitroEurope study landscape with factboxes showing options for landuse design within the current European Common Agricultural Policy framework and possibilities arising from the Danish 'green growth' initiative
- Visualization of possible scenarios and presentation of management options

4.6. An integrated database for European agricultural landscapes

Drouet, J.L., Maury, O., Dalgaard, T., Dragosits, U., Theobald, M., Sutton, M.A. Cellier, P.

Contact: Jean-Louis Drouet (drouet@grignon.inra.fr)

The NitroEurope Integrated Project (EC FP6, 2006-2011) aims to analyse the nitrogen cycle in order to quantify the effect of reactive nitrogen on the greenhouse gas balance in Europe and propose nitrogen abatement strategies. Component 4 ('Landscape analysis') focuses on interactions that occur at the landscape scale and has two major activities: i) develop the 'NitroScape' model that integrates all the different pathways (anthropogenic, biological, atmospheric and hydrological) of nitrogen transfers and transformations at the landscape scale and ii) establish a database that integrates data collected on European landscapes for calibration and verification of the model's predictions. The poster describes the process of building the NitroEurope-C4 landscape database and its structure. This relational database has been designed to ensure consistency between data collected by different institutions and consistency between NitroScape inputs/outputs and field data regarding units and temporal and spatial resolutions. It integrates various types of data: i) meteorological data, ii) biophysical variables measured at several points within the landscape at a (typically) monthly time step, iii) farm management survey data and iv) GIS-spatial data. The biophysical variables measured include concentrations and fluxes of atmospheric NH_3 and N_2O , nitrates and ammonium concentrations within the hydrosphere, nitrogen concentration in vegetation, soil and streams. The farm management data include the structure of the farming system, management of crops, grasslands, animals, nitrogen inputs and products. The spatial data include topography, vegetation, soil, land use maps and satellite data. According to the NitroEurope policy, the database features ensure longevity and easy dissemination of data, as well as protection of ownership and intellectual property rights. The database building process and structure of the database may be used in further projects at the landscape scale.

4.7. Nitrogen fluxes and budgets in a NEU C4 site (Kervidy-Naizin, France) with high nitrogen surplus: measurements and modelling

Durand, P., Akkal, N., Flechard, C., Drouet, J., Hamon, Y., Molenat, J., Hassouna, M., Cellier, P.

Contact: Patrick Durand (patrick.durand@rennes.inra.fr)

The Kervidy-Naizin catchment has been monitored for 18 years as a part of the long term environmental observatory “ORE Agrhys” (www.inra.fr/ore_agrhys), and is one of the six landscape sites of the C4 component of the NitroEurope IP. In this 5 km² area located in Central Brittany, Western France, farming is very intensive, with a very high density of livestock (30,000 pigs, 40,000 hens and 400 dairy cows). The landuse is dominated by maize (35%), winter cereals (30%) and temporary grasslands (25%). The mechanisms responsible for the storage and transfer of mineral nitrogen in water are well known and quantified in this site, thanks to the long record of discharge and concentration measurements in groundwater and stream. Under NitroEurope, they have been completed by atmospheric measurements, i.e. NH₃ concentrations and N₂O emissions, ecosystem measurements (soil and plant N content) and by a detailed survey of the farms operating in the area. These data, combined with an agro-hydrological model (TNT2) and a deposition model, are used to assess the major fluxes of the nitrogen budgets of this landscape, considering different sub-systems: farms, agricultural plots, whole catchment. The farm gate budgets are very variable according to the farm systems, from less than 50 kgN/ha/year for farms without livestock to more than 750 kg/ha/years for farms combining dairy and pig productions. Agricultural plot budgets also vary strongly, some maize fields being grossly over-fertilized due to large pig slurry applications. The fluxes in the stream are over 60 kgN/ha/year, and the mean background NH₃ concentrations are more than 10 microg/m³, with much larger values measured downwind from the livestock buildings. The results are discussed in terms of storage and emissions in/to the different compartments and associated uncertainties.

4.8. Ammonia volatilization after slurry spreading in North Italy: comparison between eddy covariance measurements and inverse dispersion modelling

Ferrara, R.M., Loubet, B., Betrolini T., Carozzi, M., Acutis, M., Di Tommasi, P., Magliulo, V., Martinelli, N., Rana, G.

Contact: Rossana Ferrara (rossana.ferrara@entecra.it)

Ammonia (NH₃) volatilization after organic and inorganic fertilizers should be measured by means of non-invasive methodologies like micrometeorological ones in order to avoid alteration of processes involved in the phenomenon. The eddy covariance (EC) technique could be an optimal solution for monitoring NH₃, but, nowadays, it is considered a challenge by scientific

community due to the difficulties encountered in its actual application. In particular, few data are available in literature and, in general, an underestimation of NH_3 fluxes is reported by experimental trials carried out both in laboratory and field. An experimental campaign was carried out in North Italy during and after slurry spreading on bare soil at the end of March 2009. An improvement of the EC system used for the first time during a trial in South Italy in 2008 was employed for measuring the NH_3 fluxes. The EC system was equipped with a sonic anemometer (Gill-R2, UK) and a fast-response sensor for NH_3 , the compact QC-TILDAS-76 SN002-U developed by Aerodyne Research Inc. (ARI, USA). Great care was put in the setup of the system, facing the issues of power supply, thermal stability of the fast response NH_3 detector and the warming of its inlet tube to avoid inside water condensation. Moreover, the input data needed for running the inverse dispersion model "FIDES" were collected in order to compare the performance of the EC system with these simulated data. An underestimation by the EC system was recorded with respect to the FIDES simulated data, even if this underestimation was lower than the results obtained by the same EC system during the previous trial. The observed differences between the two approaches are discussed, especially in terms of flux footprint and high frequency loss corrections. These results confirm the efficacy of the above mentioned improvements, even if the question about the applicability on large scale of the EC approach to NH_3 monitoring is still open.

4.9. Nitrous oxide and methane fluxes after clear cutting and prescribed burning of boreal Norway spruce forest

Kieloaho, A.J., Aaltonen, A., Levula, J., Pumpanen, J., Pihlatie, M.

Contact: Antti-Jussi Kieloaho (antti-jussi.kieloaho@helsinki.fi)

We conducted a clear cut and prescribed burning experiment to assess their ecological effect on carbon and nitrogen cycling and greenhouse gas fluxes in boreal forest(s). In clear cut commercial wood is removed and in prescribed burning the logging residue, surface vegetation and the upper-most humus layer are burnt to promote the regeneration of the tree stand after the clear cutting.

The experimental area is situated in Hyytiälä, southern Finland, near SMEAR II measurement station (NitroEurope IP Level 3 site). The experimental area is a Norway spruce (*Picea abies*) forest (6.8 ha) on haplic podzol soil developed in a glacial till. The experimental area consists of three treatments: control (co), clear cut (cc) and prescribed burnt forest (b).

Pre-treatment measurements in the measurement area started in May 2008. The clear cutting and burning sites were clear cut in February 2009 and the prescribed burning was conducted in the end of June 2009. Nitrous oxide (N_2O) and methane (CH_4) fluxes were measured fortnightly by static chambers from May to September in 2008 and 2009. In total 24 chambers were used in the measurement area, 8 chambers in each treatment (co, cc and b). In addition, soil samples to quantify changes in the soil acidity (pH), mineral and total nitrogen contents as well as microbial biomass and microbial activity were sampled before and after the clear cutting and burning.

According to preliminary results there were no distinctive differences in N_2O or CH_4 fluxes between the control, clear cut and burning areas in 2008 before the treatments. After the

prescribed burning, we observed an immediate decrease in the CH₄ uptake, whereas no changes in N₂O fluxes were observed. This decreasing trend in CH₄ uptake was also observed in the clear cut site during July. The measurement activity in the three sites is still continuing in order to assess the potential long-term effects on carbon-nitrogen interactions and greenhouse gas fluxes.

4.10. An open hydrological model toolkit for upsacing plot scale N turn over models

Kraft, P., Vaché, K.B., Multsch, S., Frede, H.G., Breuer, L.

Contact: Philipp Kraft (philipp.kraft@umwelt.uni-giessen.de)

In the NitroEurope IP different models for the simulation of biogeochemical turnover processes at the plot scale are developed. On the landscape scale the connection between upslope application of nitrogen and downslope effects, e.g. in the riparian zone by denitrification, are of major importance. To predict the effects of lateral distribution of dissolved N on the landscape scale, a modeling framework of lateral transport between plots is needed.

According to the local geologic and climatic properties the major hydrologic flow paths can differ widely. Choosing a single hydrologic model, which emphasizes one transport path, like interflow, shallow aquifers or surface runoff only, may be inadequate for capturing the connection of the plot scale models and might neglect the dominant process of a specific landscape.

We therefore developed the Catchment Modeling Framework CMF for the connection of plot scaled nutrient turn over models. This tool kit allows to set up different hydrological models for different dominant flow paths and test the various flow path simulations and N turnover predictions against measured data. The tool kit is implemented as an extension to the programming language Python, thus creating a "hydrologic" language. Exchanges of matter flux between model domains is easily incorporated using flux exchange interfaces.

The application of CMF with different realisations of flow paths in virtual hill slopes is demonstrated. We further show the interaction of CMF with a plant growth model and a proxy N turn over model.

4.11. A determination of ammonia concentration over crop fields at different locations in the vicinity of Turew

Kulek, B.

Contact: Beata Kulek (B.Kulek@interia.eu)

An investigation of variation of ammonia concentration during all one year over different crop fields in the vicinity of Turew (Wielkopolska, Poland) was a purpose of this study. Passive ALPHA samplers (of Centre for Ecology and Hydrology production, Edinburgh) with filters absorbing ammonia were attached to stakes at 1.5 m level over the surface of the ground.

Exposure time was approximately one month. Ammonia concentration in air (for each location) was calculated from ammonium ion concentration found in water solution obtained from rinsing a filter using a spectrophotometric method. It was stated that ammonia concentration depends on: the type of applied fertilisers (mineral and organic), a presence of organic substance accumulated on the field, crops species and on air temperature.

4.12. Variations of Inorganic Nitrogen Content in the Black Soils in the South of Ukraine Under Conditions of Crop Rotation

Medinets, V., Bilanchin, Ya., Medinets, S., Pitsyk, V.

Contact: Volodymyr Medinets (medinets@te.net.ua)

The presentation considers variations of inorganic nitrogen mobile forms' content in the "Petrodolinskoe" site studied by Odessa National I.I. Mechnikov University for the last three years (NitroEurope, Level 2 site).

The results of laboratory studies have shown that nitrogen content in soil varies during year and change very much with seasons. Certainly, huge immediate influence on the content of inorganic nitrogen in consumable forms is caused by the sources and sinks of nitrogen in this biocoenosis. As the main sources we should consider fertilisers applied during year and nitrogen-fixing biota, while the sinks are the cultivated crops and denitrifiers. Of course one should not forget that intensity of applied and fixed nitrogen consumption and the scale of nitrogen containing compounds elimination in the form of microorganisms' waste products depend greatly on abiotic factors of the environment: temperature, humidity, radiation etc.

In the paper we tried to follow in somewhat simplified way the distribution of nitrogen compounds from/into the soil depending on the crop cultivated and the scheme of fertilizers application. In recent years crop rotation looked the following:

- i. in 2007 they were growing onions and fertilizers were applied intensively ($114 \text{ kg ha}^{-1} \text{ y}^{-1}$);
- ii. in 2008 they were growing tomatoes and the scheme of fertilization was more moderate - $28 \text{ kg ha}^{-1} \text{ y}^{-1}$ during the season;
- iii. in 2009 they were growing barley, no fertilizers were used.

4.13. CoTAG System in Ukrainian Arable Land: Preliminary Results of NH₃ Concentrations and Fluxes Measurement

Medinets, V., Medinets, S., Proshchenko, V., Famulari, D., Twigg, M., Tang, S., Duyzer, J., Chojnicki, B., Olejnik, J.

Contact: Sergiy Medinets (s.medinets@gmail.com)

Conditional Time Averaged Gradient (COTAG) system is a new low-cost system for the measurements of N-compounds by using a combination of DELTA system and sonic

anemometer. These systems were constructed by Poznan University of Life Science and distributed to NEU members, who are involved in such measurements. COTAG system was installed on the southern black soils in "Petrodolinsko" L2 site, Ukraine, and started to measure since 7 August, 2009.

In the framework of the approved programme of studies our station measures only ammonia concentrations and fluxes. Chemical analyses of denuders are done by the chemical laboratory of the Regional Centre for Integrated Environmental Monitoring and Ecological Studies of Odessa National I. I. Mechnikov University.

The presentation shows preliminary results of NH_3 concentrations and fluxes measurements as well as the percentage of atmospheric stability classes distribution during the period of studies.

4.14. High precision and site selective measurements of ambient N_2O isotopomers by QCLAS

Mohn, J., Tuzson, B., Guggenheim, C., Vollmer, M.K., Emmenegger, L.

Contact: Joachim Mohn (joachim.mohn@empa.ch)

The intramolecular distribution of ^{15}N in N_2O can be used to obtain important information on the geochemical cycle of N_2O because many biological and chemical processes have distinct isotopic signatures. N_2O is a linear, non-symmetric molecule (N–N–O), with one nitrogen atom at the centre (a site) and one at the end (b site). Therefore, one can distinguish between two structural isomers containing one heavy isotope of nitrogen, namely $^{14}\text{N}^{15}\text{N}^{16}\text{O}$ and $^{15}\text{N}^{14}\text{N}^{16}\text{O}$, referred as ^{15}Na and ^{15}Nb , respectively.

Until recently, N_2O isotopomer studies at ambient concentrations were mainly limited by the lack of suitable analytical techniques. The standard methodology, laboratory-based isotope-ratio mass-spectrometry (IRMS) requires flask sampling and thus significantly constrains the ability to characterize the variations in N_2O isotopic species at time-scales relevant to environmental processes. We have developed a field-deployable quantum cascade laser absorption spectrometer (QCLAS) and a fully-automated sampling unit. The coupling of QCLAS and preconcentration will allow, for the first time, the semi-continuous high precision analysis of ambient N_2O isotopomer ratios. Thereby, it will be possible to study the site-specific isotopic signature of N_2O source and sink processes in various ecosystems under changing environmental conditions. N_2O isotopic signatures can then be employed to quantitatively apportion N_2O production on a regional or global scale.

4.15. Variability of the response of nitrogen mass balance of 9 catchments to a water pollution mitigation programme: a modelling study

Moreau, P., Durand, P., Ferchaud, F., Raimbault, T., Baudhuin, P., Gibon, C.

Contact: Pierre Moreau (pierre.moreau@rennes.inra.fr)

To meet the objectives of the Water Framework Directive in terms of nitrate pollution of surface water, numerous mitigation options have been proposed. They often result from

centralised decision and could therefore overlook site specificities, leading to a diversity of efficiency. To support stakeholders' decision prior to the implementation of regulations, scenario analysis by models can be used as a prospective approach.

In this context, a scenario of reduction of the limits of permitted fertilization loads (RF) was tested with INCA (Integrated Nitrogen in Catchments) model on nine catchments of Brittany, Western France. These catchments differ not only in terms of nitrogen surplus but also in hydrological functioning. The objective of the study was to describe the variety of the efficiency of this measure of input reduction in terms of reduction of nitrate stream fluxes and to identify the main reasons for these variations.

In this study, INCA was not used in the standard way: the subcatchment-base structure was used as a farm-group structure to cope with the diversity and complexity of the farming systems operating in the area.

Mass balances at the catchment scale show the effects of the RF scenario on the main N outputs from the catchment. This highlighted a common trend in all the watersheds: uptake reduction and the depletion of soil and groundwater stores decrease markedly RF efficiency. No relation was found between RF efficiency and hydrological functioning. Finally, RF efficiency was not related to the magnitude of the fertilization reduction while some relation appears between RF efficiency and fertilization reductions recorded between 2000 and 2006, underlining the predominance of memory effect of the systems.

Even if some oversimplifications of agricultural practices are unavoidable with INCA, confronting scenario efficiency, catchments characteristics and N mass balance enhances comprehension of scenario effect in a decision support application.

4.16. Toward the development of a 'Quasi proportional eddy accumulation' system for flux measurements of N₂O and other trace

Nicolini, G., Fratini, G., Stefani, P., Valentini, R.

Contact: Giacomo Nicolini (g.nicolini@unitus.it)

Eddy Covariance (EC) is the most defensible technique for landscape scale measurement of atmosphere/biosphere exchange of main greenhouse gases (CO₂ and H₂O). Recently, the interest of the scientific community is increased for ultra-trace gases like N₂O, NO_x, CO, CH₄, O₃, as they may exert an even higher impact on global warming, even though their atmospheric concentration is much lower with respect to CO₂ and H₂O. Indeed, N₂O have a potential climatic impact 296 times higher than CO₂ and its global burden continues to rise linearly. Main N₂O sources are identified, however there is still uncertainty in their strength, as they are extremely variable in time and space. Flux measurement of low-concentration gases by EC is still problematic, since the short time response required by the technique, contrasts with an adequate accuracy of the gas concentration measurement. Currently, a few commercially available gas analyzers allow these performances but they are still rather expensive and demanding in terms of management. As an alternative to EC, the Eddy Accumulation (EA) technique has interesting potential benefits when fluxes of low-concentration gas are targeted. Basing on the same theoretical ground of EC, the EA does not require fast response gas analyzers. Though it requires sampling air volumes proportional to the instantaneous vertical

wind component (the co-called proportional sampling).

Here, we present the current status of development of an EA system, conceived for continuous N₂O flux monitoring, but employable with any other passive atmospheric scalar. As a strictly proportional sampling is still a goal to be achieved, we introduce the concept of “Quasi-Proportional Eddy Accumulation”. By means of laboratory tests and numerical simulations, we show here that a quasi-proportional sampling system allows flow estimates as close as 3-5% to EC fluxes. Furthermore, a strategy is addressed to correct the direct EA flux estimates for the effect of non-proportionality.

4.17. A new generic database software for long-term data storage and retrieval: conception, birth and first months

Owen, S., Leaver, D., Bealey, B., Wilson, R.

Contact: Susan Owen (susa1@ceh.ac.uk)

To fulfil the data storage and retrieval requirements for NitroEurope, we developed a bespoke database software in an attractive on-line environment. The challenges included (1) large diversity and volume of data, many at very high temporal resolution, (2) multiple submission of data during the project, (3) the need to cope with changing requirements, (4) a large user community, and (5) data security. The resulting software allows great flexibility for any time-series or one-off data, making it suitable for a wide range of other applications.

NEU scientists are collecting large volumes of field and experimental data from sites all over Europe at high temporal resolution. Therefore the database has to provide easy upload of data from EXCEL workbooks, and easy extraction of data for analyses, interpretation and modelling. Nearly 2000 different data items are collected at the 13 super sites alone (C1L3), along with supporting plant-soil experimental data (A1.4). In addition, data need to be stored and accessed for 9 low-cost flux sites (C1L2), and for more than 50 C1L1 sites making measurements for inferential modelling. Data from C2 measurements at ~35 sites are also stored, and it is planned to accommodate C3 model input and output data, with attached model code.

A reporting wizard enables selection of any fields from uploaded data, and presents “reports” as downloadable EXCEL or CSV files, or as an on-screen graphs. High temporal resolution data can be averaged for defined frequencies (eg 30 minute data averaged to hourly), and can be grouped to present average trends, eg diurnal. The software has been adopted for EMEP contractual periodic reporting, and for CEH’s micrometeorology data. It is planned to expand the database content and capability in the framework of a future European consortium, for “European Nutrient and Climate Observations for Research in Ecosystems”. Our poster illustrates the database development so far, along with a live demonstration. ”

4.18. What is an ideal chamber design, measurement protocol and flux calculation method to measure greenhouse gas fluxes from soils?

Pihlatie, M., Riis Christiansen, J., Aaltonen, H., Korhonen, J., Nordbo, A., Rasilo, T., Benanti, G., Giebel, M., Helmy, M., Hirvensalo, J., Jones, R., Juszcak, R., Klefoth, R., Lobo do Vale, R., Paula Rosa, A., Schreiber, P., Serça, D., Vicca, S., Wolf, B., Pumpanen, J.

Contact: Mari Pihlatie (mari.pihlatie@helsinki.fi)

Soil fluxes of the greenhouse gases nitrous oxide (N₂O) and methane (CH₄) are often measured by closed static chambers. Chamber size, shape and material, and the measurement protocol substantially affect the flux of the target gas. Most chamber types tend to underestimate trace gas fluxes from soils by slowing down the gas diffusion from the soil to the chamber headspace during the measurement. In addition, an inappropriate flux calculation method may lead to severe under- or overestimations of the true gas fluxes.

To test static chambers for measuring N₂O and CH₄ fluxes from soils, we organized a chamber calibration campaign at Hyytiälä Forestry Field Station, Southern Finland, during August-October 2008. We tested 15 static chambers for five N₂O and CH₄ flux levels under three soil moisture and porosity conditions in a system described by Pumpanen et al. (2004). The main aims of the campaign were to quantitatively assess the uncertainties and errors related to static chamber designs and the measurement protocol, and to evaluate the suitability of different flux calculation methods.

We found that most of the tested static chambers either over- or underestimated the N₂O and CH₄ fluxes, and the magnitude of over- or underestimation remained near constant regardless of flux level for each of the chambers. Chamber designs differed from each other and the sampling protocol strongly influenced the gas concentration development inside the chambers. In addition, choosing an inappropriate flux calculation method, often a linear regression, led in most cases to large underestimations in the flux estimates. Here we show the main results of the chamber inter-comparison and provide guidelines for the measurement protocol and flux calculation method.

4.19. Ammonia concentration and flux measurements on an agricultural landscape near Bjerringbro, Denmark

Pogány, A., Weidinger, T., Theobald, M., Schelde, K., Bienkowski, J., Bordás, A., Bozóki, Z., Eredics, A., Hensen, A., Janku, K., Kiss, G., Kraai, A., Istenes, Z., Mohácsi, A.

Contact: Andrea Pogány (andrea@titan.physx.u-szeged.hu)

As a part of the NitroEurope common field experiment, ammonia concentrations were measured by various methods on an agricultural field near Bjerringbro, Denmark in April 2009. Several sources of ammonia (pig farms, nearby fertilized fields) were present in the landscape and the

field itself was also fertilized with pig slurry during the campaign.

Instrumentation used for measuring ammonia concentrations included two wet-chemical (AMANDA) instruments and two photoacoustic instruments (a mid-IR CO₂ laser based Nitolux and a self-developed near-IR diode laser based WaSul instrument). The WaSul instrument was operated in gradient configuration, which also enables the calculation of ammonia fluxes. The instruments were placed at different points of the field to gain more information on the spatial concentration distribution.

A comprehensive micrometeorological station was also set up in the landscape for calculation of standard meteorological parameters, radiation and energy budget components using eddy covariance, gradient and Bowen ratio methods. Soil temperature and moisture were also measured.

Ammonia concentration data measured by the different instruments and wind speed and direction data were used to estimate the location of ammonia sources within the landscape. After fertilization of the field ammonia emission fluxes were calculated from the gradient data.

4.20. Site scale to regional estimates - comparison between two terrestrial ecosystem model, O-CN and CERES-EGC

Prieur, V., Lehuger, S., Chaumartin, F., Zaehle, S., Schulz, M., Gabrielle, B.

Contact: Vincent Prieur (vincent.prieur@lscce.ipsl.fr)

Nitrous oxide is one of the main biogenic greenhouse gases contributing to the global warming potential of terrestrial ecosystems. Estimating the nitrogen fluxes and evaluating the impact of anthropogenic pressure (land-use change, fertilizer, agricultural practices, local pollution ...) becomes essential in view of a management of these anthropogenic sources.

Two different types of ecosystem models, coupling the carbon and nitrogen cycles, are implemented to evaluate the nitrous oxide fluxes at site and regional scales : the terrestrial ecosystem model O-CN, and the biophysical crop model CERES-EGC. Calibration and validation of the models at site scale and in France reveals the differences between the two model approaches, on the process-level, on large scale for O-CN and site-specific for CERES-EGC. Having a detailed forcing dataset on soil properties and crop management and a good representation of soil hydrology seems essential to capture the temporal dynamics of N₂O emissions. Predicted regional and global estimates are found in the observed ranges for individual vegetation types and global biomes. Comparison with emissions inventories such as EDGAR and GEIA is made and discuss.

4.21. Greenhouse Gas Emissions from Danish Agriculture 2050

T. Dalgaard, J.E. Hermansen, S.O. Petersen, B.M. Petersen, T. Kristensen, N.J. Hutchings and J.E. Olesen

Contact: Tommy Dalgaard (tommy.dalgaard@agrsci.dk)

Denmark has one of the most intensive agricultural production systems in the world, dominated by major exports of meat and dairy products. Greenhouse gas emissions from agriculture therefore account for a significant part of the total Danish emissions. Consequently, much attention is currently given to explore potential strategies for reducing agricultural emissions, and strategies to increase bioenergy production within agriculture. This paper presents results from a Danish study estimating agricultural greenhouse gas emissions in the form of methane, nitrous oxide and carbon dioxide (including carbon sources and sinks) from Danish agriculture 1990-2010, and projecting possible developments towards 2050. The results indicate that a 50% reduction of agricultural emissions by 2050 relative to 1990 is realistic, and in addition the bioenergy production could be doubled. In this context, a catalogue of possible measures to reduce emissions is presented, and the effects of selected future scenarios for the combination of these measures are quantified and discussed.

4.22. Spatial and temporal dynamic of N along a transect of Piana del Sele, Italy

Oliva, M., Vitale, L., Palumbo, I., Buonanno, M., Magliulo, P., Alfieri, S., Ottaiano, L., Bertolini, T., Di Tommasi, P., Ranucci, S., Magliulo, V.

Contact: Marc Oliva (marcoliva@alice.it)

Nitrogen cycle in agro-ecosystems is strongly dependent on crop management so that in order to model N dynamics at the scale of composite landscapes it is mandatory to identify and monitor the main N sinks and sources - as well as detailing soil characteristics and crop management. In Piana del Sele (Eboli, Salerno, Italy), the southernmost study area within the landscape exercise of NitroEurope-IP European project, a detailed inventory of land use and crop management as well as a series of verification measurements were carried out in 2009. The main 54 farms were surveyed and a GIS compiled mapping fields and buildings as well as soil characteristics. A soil map was assessed on the basis of intensive field campaigns carried out on the basis of an *ad hoc* developed protocol following a geomorphological approach. Soil properties essayed in pedological campaigns and by laboratory determinations were assigned to areas with homogeneous soil classes.

Spatial and temporal variability of N in the atmosphere, ground water and soil was assessed along a NE transect connecting two animal farms accounting for most of the N sources within the study area. Soil, water and air samples were collected in 12 different locations along the transect. At each site, the soil was sampled within and below the root zone for the determination of NO_3^- and NH_4^+ concentration; ground water was collected up to 3 m depth to determine NO_3^- and NH_4^+ concentration, while air NH_4^+ was sampled by means of alfa-samplers.

Preliminary analysis of collected data show that most of NH_3 emissions originated from Carrozza farm, a water buffalo animal farm sited on the SW border of the domain. Lower concentrations were detected downwind of Carrozza farm, near Hospital site. Seasonal trends of

NH₃ air concentrations show an increase in air NH₃ during the summertime. NO₃⁻ and NH₄⁺ concentrations in ground water during spring ranged between 107.6 and 0.73 mg l⁻¹ and 0.34 and 0.1 mg l⁻¹, respectively.

5. Assessment of present and future nitrogen and green house gas fluxes at large regional scales in response to human influence

5.1. Developing stratified N₂O emission functions for Europe

Leip, A., Winiwarter, W.

Contact: Adrian Leip (adrian.leip@jrc.ec.europa.eu)

There is no doubt that N₂O fluxes from agricultural soils have only limited dependence on the amount of nitrogen added to the soil in the year of crop growth. Amongst the many factors that influence the magnitude of N₂O fluxes are soil parameters (organic carbon content, soil texture and pH), ways of fertilizer application (types of fertilizer applied, timing) and meteorological conditions. Yet, in most assessments of anthropogenic GHG fluxes from agriculture, constant emission factors are used, in many cases the default IPCC factors of 1.25% or 1.0% of total anthropogenic N-input.

We investigate the possibility to replace this – so-called Tier 1 – approach with stratified emissions functions that take into account both the spatial variability of the environmental conditions and the fact that more than the absolute quantity of N input, its magnitude in relation with crop demand is significantly determining the amount of nitrogen lost to the environment.

For this purpose we use the process-based model DNDC to simulate N₂O fluxes at a large number of spatial calculation units (about 200,000 for EU27) for up to three crops per unit and for ten different meteorological years. The objective is (i) to check the linearity-hypothesis of N₂O fluxes with mineral fertilizer and manure nitrogen input; and to assess further the impact of the following scenarios against a default situation: (ii) precision farming; (iii) organic farming; (iv) extensive farming; (v) implementation of the nitrate directive; and (vi) biofuels. The default situation is defined by disaggregating an ex-post simulation with an economic model for agriculture. This model, CAPRI, provides data on land use, mineral fertilizer and manure nitrogen application, and yield for all crops according to EUROSTAT statistics for each spatial calculation unit. The scenarios have been interpreted in terms of these input parameters. E.g., the extensive farming scenario was interpreted as reduced mineral fertilizer application, which at the same time results in reduced yield; in the organic-farming scenario additional application of manure nitrogen was assumed as a compensation, up to a limit of 170 kg N/ha.

We use the resulting 10 million data points to derive national emission functions, upscaled from the spatial calculation units that reflect the agricultural area of a country. These emission functions, reflecting the full range represented by the scenarios, are compared against the IPCC default factors used in the countries.



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