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Innovative solutions for
SUSTAINABLE MANAGEMENT OF NITROGEN

Conference proceedings

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Preface

At a pub in Edinburgh, right after the presentation of the European Nitrogen Assessment (2011) and the final conference of the www.NitroEurope.eu project, the idea of a Danish Nitrogen Research Alliance spawned. The group of Danish researchers gathered, saw the benefits from allying central Danish actors to facilitate a sustainable use of Nitrogen, and thanks to seed money from the Aarhus University Research Foundation a successful application for The Danish Research Council for Strategic Research, now Innovation Fund Denmark, was formulated.

The Danish Nitrogen Research Alliance (www.dNmark.org) serves as a fruitful network for a range of actors, including researchers across multiple disciplines and institutions and a long list of private and public partners, investing significantly in the alliance. A central aim of the alliance is to share knowledge, both nationally and internationally, and we thank you for all these contributions, which are reflected in the present international conference (http://sustainablenconference.dnmark.org), and our collaborators in related international and national projects.

With a total of 6 PhD and 7 post-doc projects, one of the main products of the dNmark.org research alliance is education and competence development for the next generation, in interaction with state of the art N research environments. With the current high focus on development of the bioeconomy, and a new paradigm for Nitrogen regulation in Denmark, to meet the standards of EU Directives and comply with local and transboundary pollution problems, the need for new knowledge has only increased during the lifetime of the alliance.

Denmark as a case is especially interesting in an international perspective. The strong record with decades of research based solutions to the nitrogen pollution problem in combination with initiatives to facilitate a higher N efficiency and value creation in agriculture and food chains attracts interest, and serves as a basis for guidance to farmers and policy makers internationally. This include work under the UN Task Force on Reactive Nitrogen, and the annual meeting (TFRN-12) co-hosted with the present conference, and a defined need both in Denmark and internationally to find new solutions to a more sustainable use of nitrogen with co-benefits to the economy and for air, water, soil and climate protection.

On this background, we welcome to the conference on “Innovative Solutions for Sustainable Management of Nitrogen”, as a starting point for further knowledge sharing and development.

Tommy Dalgaard and Jørgen E. Olesen,

Co-chairs of the www.dNmark.org Research Alliance and the http://sustainableNconference.dnmark.org scientific conference committee.

Aarhus University, Department of Agroecology,

June 2017

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Posters: Local N solutions

Posters: Nitrogen abatement policies

Posters: Sustainable consumption

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Sustainable Nitrogen Management in Denmark

Tommy Dalgaard[1], Steen Brock[2], Morten Graversgaard[1], Birgitte Hansen[3], Fatemeh Hashemi[1], Berit Hasler[4], Ole Hertel[4], Nicholas John Hutchings[1], Brian H. Jacobsen[5], Lars Stoumann Jensen[6], Chris Kjeldsen[1], Jørgen E. Olesen[1], Jan K. Schjørring[6], Torben Sigsgaard[7], Peter Stubkjær Andersen[8], Mette Termansen[4], Henrik Vejre[8], Mette Vestergaard Odgaard[1], Wim de Vries[9], Irene A. Wiborg[10]

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Background

Since the mid 1980s, the surplus of nitrogen (N) from Danish agriculture, defined as the gap between N-import and N-export, has decreased significantly, and the overall N-efficiency (defined as N taken up by plants as ratio of the added amount) has more than doubled, from about 20% in 1980 to more than 40% today (Figure 1).

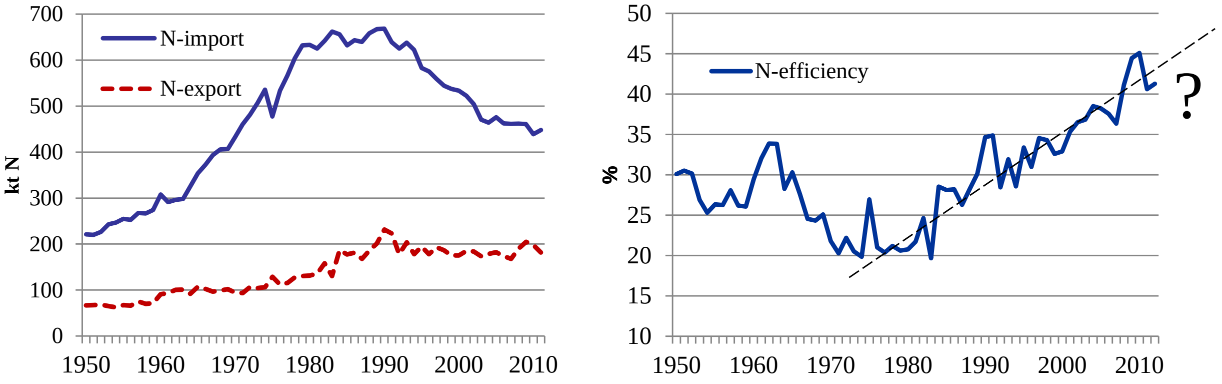

Figure 1. Total sum of N imports to- and sum of N exports in products from Danish agriculture, and overall N use efficiency for Danish agriculture over the period 1950-2012 (updated after Dalgaard et al., 2014). The question mark indicates the potential effect of various new measures which may further increase the N use efficiency and reduce N losses.

The cause behind this remarkable development is an effective interaction between a series of political action plans and legal acts, improved agronomic techniques and large investment in new and more N efficient technologies. However, the costs have also been high (estimated to 340 x 10^6 € yr^{-1}, Dalgaard et al., 2014), and still there is a significant gap between N-imports and N-exports and consequently a high potential for an improved N-efficiency.

The aim of this presentation is on this background: i) to understand the causes and effects behind this development, and ii) explore sustainable solutions to facilitate a further development towards a more sustainable N management with a lower N-surplus and higher N-efficiency, in combination with economic development and the protection of the natural environment and the general public health.

The need for an integrated approach

In general, the Danish N policies have focused strongly on separate measures, in particular targeting the reduction of N-leaching to the aquatic environment and reduction of ammonia volatilization to the air via input side measures, manure management and handling measures, and measures to reduce losses from the cropping system (for e.g. catch crops). However, as the reactive nitrogen (Nr) input cascades through the agricultural and natural ecosystems, there are important links between the different types of losses (Figure 2), calling for an integrated approach where effects of co-benefits (or drawbacks) of different management options are incorporated. For example, the improved efficiency indicated in Figure 1 is also a very important factor behind reduced greenhouse gas emissions from Danish agriculture, both directly via reduced nitrous oxide emissions, but also indirectly when improved N efficiency reduces fossil energy consumption for fertilizer production and methane emissions from livestock production systems (Dalgaard et al., 2011).

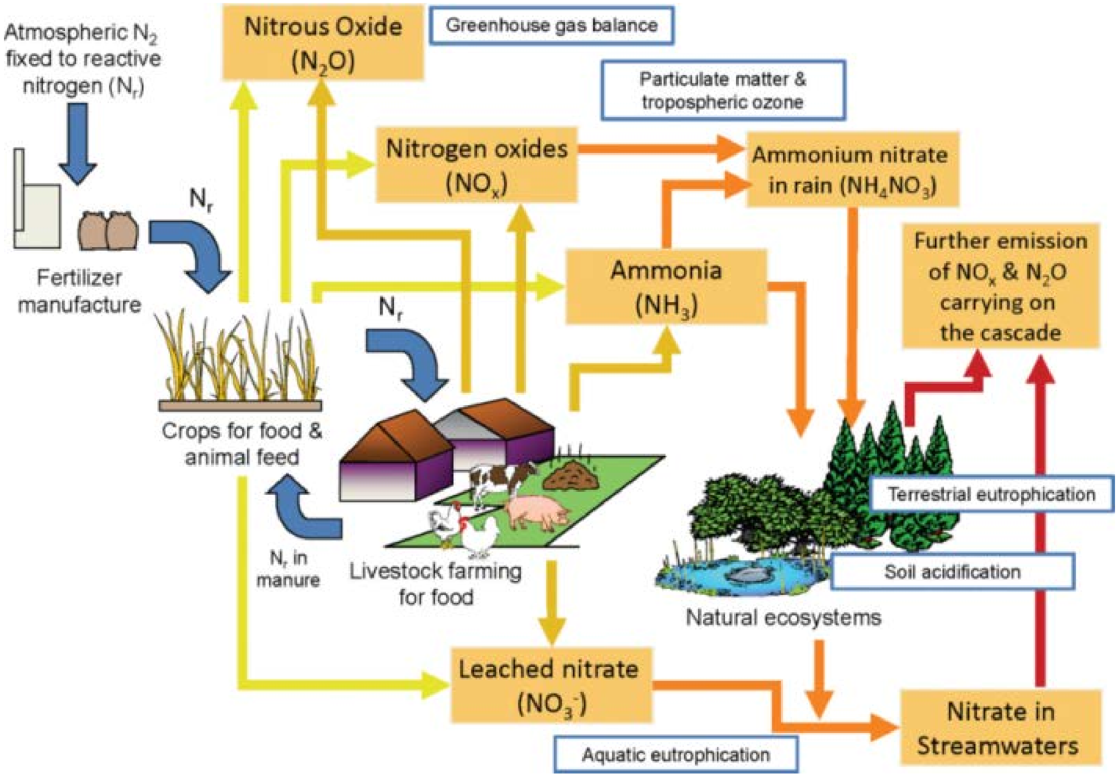

Figure 2. A simplified representation of the human impact on the nitrogen cycle and the associated cascading effects. Blue arrows show intended anthropogenic Nr flows, while the other arrows show unintended flows (Sutton et al., 2011).

Based on guidance from the Task Force and Reactive Nitrogen Expert Panel on Nitrogen Budgets (http://www.clrtap-tfrn.org/epnb), a method to assess and overview all Danish N flows has been developed in context of the www.dNmark.org Research Alliance (Hutchings et al., 2014). Based on this method the flows behind the development depicted in Figure 1 and the links between types of input and output (Figure 2) are revealed (Figure 3). The management of agriculture and food systems is obviously crucial for the significantly reduced environmental losses from 1990 to 2010, and thereby for the understanding of future mitigation options. The fluxes connecting compartments are indications as to where the future regulation options occur.

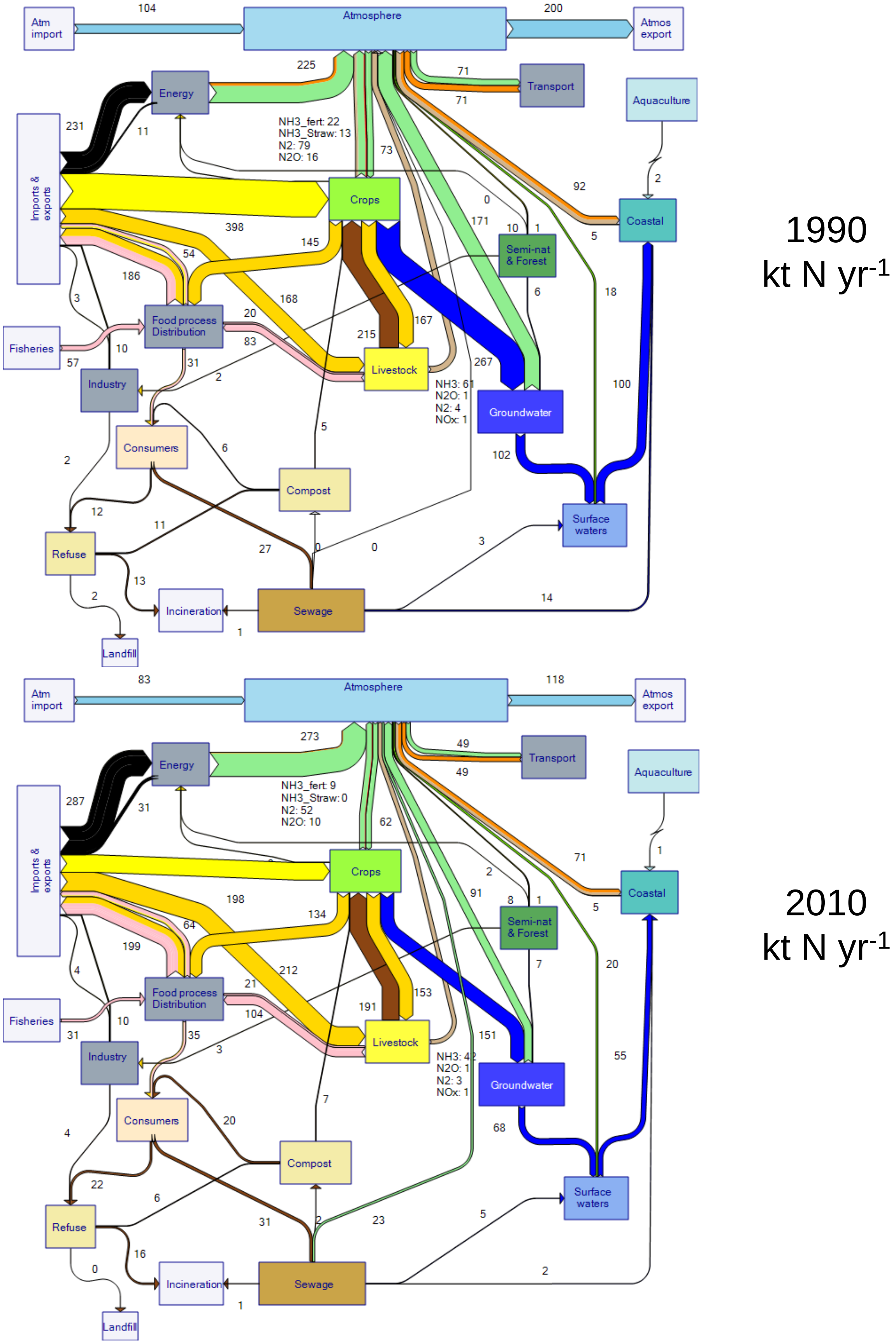

Figure 3. The N balance, N inputs and N flows assessed for Denmark 1990 and 2010 (Hutchings et al., 2014).

A New Paradigm for Nitrogen Management

In 2016, The Danish Government introduced a new action plan, with a nitrogen regulation tailored to local N reduction targets rather than the general N reduction goals known from previous action plans. It is a large challenge to implement this, and the knowledge generated in the subprojects of the www.dNmark.org Research Alliance and the related PhD and post-doc projects focusing on different compartments of the N landscape (Figure 1) is important in this context.

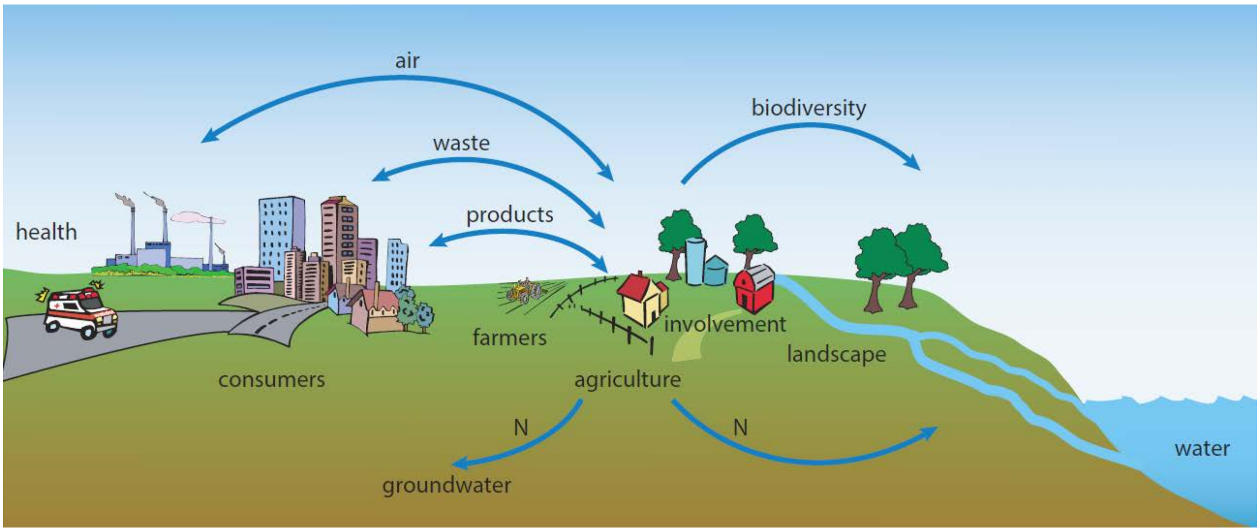

Figure 4. Focus areas for the www.dNmark.org research alliance.

As of 2017, a new scheme introducing catchment advisors (“oplandskonsulenter”) is implemented, inspired by the dNmark pilot landscape study sites, and the geographically tailored N regulation will be implemented stepwise over the coming years, with significantly enhanced implementation of measures like wetlands, mini-wetlands, afforestation and other landscape-level buffers which reduce Nr before it reaches vulnerable recipients. The above-mentioned integrated, combined effect assessments of these measures is important, both at the landscape and the national scale, and is the turning point for both the further solution scenarios assessments and publication in the www.dNmark.org alliance and the ongoing international Task Force on Reactive Nitrogen development of joined-up nitrogen guidance documents for air, water and climate co-benefits.

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New opportunities for increased N use efficiency in a circular economy

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Background and aims

Currently low N use efficiencies in the food chain often results in less than 15% of exogenous N ending up on the consumer plate. Key aspects for improvement of N use efficiency include new strategies for better N utilization in crop production, livestock production and processing of raw materials into food products. Furthermore, there is scope to increase the amount of agricultural fertilisation in the EU provided by recycled nutrients and recent EU circular economy policies promote recovery and recycling of excess nutrients from agricultural, industrial and urban waste streams into products that can be used as agricultural fertilisers.

This presentation will focus on technological approaches to increase the recycling and reuse of inevitable side stream N losses occurring in steps of the food chain, e.g. separation, acidification and biogas, recycling of N in crop residues and urban waste (sludge and household waste).

Methods

Organic wastes with potential for agricultural application as bio-based fertilisers can be broadly classified into three categories: i) animal-based organic wastes such as manure and urine, raw or processed (see below ii) green manures based on plant sources, and iii) urban wastes such as industrial and sewage sludges and organic household waste. Many of these bio-based fertilisers have the potential to fulfil crop nutrient (N, P, K, S, micronutrient) requirements, but the main challenges with their use includes i) low nutrient concentrations and bulkiness, ii) slow/uncertain nutrient availability, iii) inappropriate nutrient ratios, iv) higher risk of environmental emissions, and v) odour, biosecurity and other nuisances for neighbours. Technological options for both processing and field application will be covered as well as end-user perceptions and preferences, and market development perspectives of such bio-based fertilisers.

Results and discussion

Bio-based fertilisers can be processed in a number of ways to separate components (e.g. manure separation to improve handling and optimise nutrient content), recover energy (e.g. anaerobic digestion, AD), remove unwanted substances (such as pathogens, e.g. through composting), or retain nutrients in an available form (acidification, drying etc.). Depending on the technology used, processing may improve manageability, nutrient use efficiency and fertiliser value, or soil quality improvements, hence economic value. Developments of modern application technologies (i.e. band-spreading, injection, acidification, online nutrient determination) may help overcome some of the challenges listed above. Furthermore, bio-based fertilisers will contribute both valuable organic matter, improving soil fertility and quality, but also in most cases organically bound N, which will mineralise slowly, providing both residual value to subsequent crops but also risk of leaching loss during uncropped periods; therefore prediction methods to include this in nutrient management plans are essential. Finally, farmers are the primary end-users of these recycled and bio-based fertiliser products, and it is important to understand their requirements and decision-making processes underlying the use of such processed and unprocessed organic waste-based fertilisers.

Conclusion and outlook

With recent developments of bio-waste processing and application technologies it is possible to increase N recycling and supply full crop nutrition with bio-based fertilisation. However, there are still many barriers (i.e. end-user acceptance, economic profitability, regulations, market development) to realise the full potential of nutrient recycling from manures, waste and residues in a circular economy.

The California Nitrogen Assessment: Learnings and Outcomes[1]

Thomas Tomich[1], Kate Scow[2], Randy Dahlgren[2], Sonja Brodt[1], Aubrey Thompson[1]

[1]Agricultural Sustainability Institute, University of California, Davis; [2]Department of Land, Air, and Water Resources, University of California, Davis

Californians' quality of life depends on our abundant food and vibrant agricultural landscapes. All Californians have a stake in a thriving agricultural sector and agricultural communities in our state, both now and for future generations. Nitrogen, in various reactive forms, is indispensable to the productivity of California agriculture. And yet, only about half the nitrogen applied ends up where we intend; the balance leaks, polluting our air and water, with detrimental effects on our environment and human health.

California can be a leader in seeking a better balance between managing nitrogen as an essential agricultural input and minimizing its negative impacts on communities and the environment. Getting California's nitrogen balance right—increasing benefits while reducing costly side effects—requires broad collaboration over the coming years, with farmers and ranchers leading the way to produce solutions.

The California Nitrogen Assessment (CNA) is the first comprehensive accounting of nitrogen at a state level for California.

The goals of the CNA are to:

- Provide useful insights for stakeholders into the balance between the benefits of nitrogen in various aspects of our modern economy, including agriculture, and the effects of surplus nitrogen in the environment
- Compare options, including practices and policies, for improving the management of nitrogen and mitigating the negative impacts of surplus nitrogen in the environment
- Effectively link science with action and to produce information that informs both policy and field-level practice

The CNA is a synthesis of existing research to answer the questions:

- What is driving nitrogen use?
- How much nitrogen enters the state through new sources?
- What are the ways that nitrogen ultimately enters and affects the environment?
- What are nitrogen's impacts on the environment and human well-being?
- What are the technological and policy options to minimize nitrogen's negative effects while sustaining the vitality of agriculture?

The CNA was launched in 2009 and the text for the final publication was finalized in July, 2015. Though there are many relevant recent and ongoing policy initiatives, the assessment is not a review of the current policy arena in California.

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[1] This abstract is an excerpt of the Executive Summary for the California Nitrogen Assessment. The full Executive Summary is available on our website. The California Nitrogen Assessment book is available through UC Press.

The CNA followed established protocols for integrated assessments. The CNA synthesized the large body of existing scientific literature on nitrogen, used it to analyze patterns and trends, and assessed the quality of information and knowledge about key issues.

The CNA was developed through participatory design, with stakeholder consultation to guide the research agenda to ensure its process and outputs are considered legitimate by a broad range of stakeholders. The assessment's findings underwent a multistage peer review process, including consecutive reviews by over 50 scientific experts, review by a Stakeholder Advisory Committee, and an open public comment period. Ten distinguished review editors ensured all comments received appropriate attention and responses from authors.

Drivers of Nitrogen in California

Many global factors influence nitrogen in California including **human population and economic growth, market opportunities for California commodities, agricultural production costs and technological change, and policies targeting nitrogen in California.**

Along with global factors that affect nitrogen, everyday actions of Californians radically alter the nitrogen cycle. Six actions fundamentally change nitrogen cycling in the state: **Nitrogen fertilizer use (both synthetic & organic sources), manure management, fossil fuel combustion, industrial processes, wastewater management, and changes in land use.** Each of these drivers has intensified since 1980.

A California Nitrogen Mass Balance for 2005

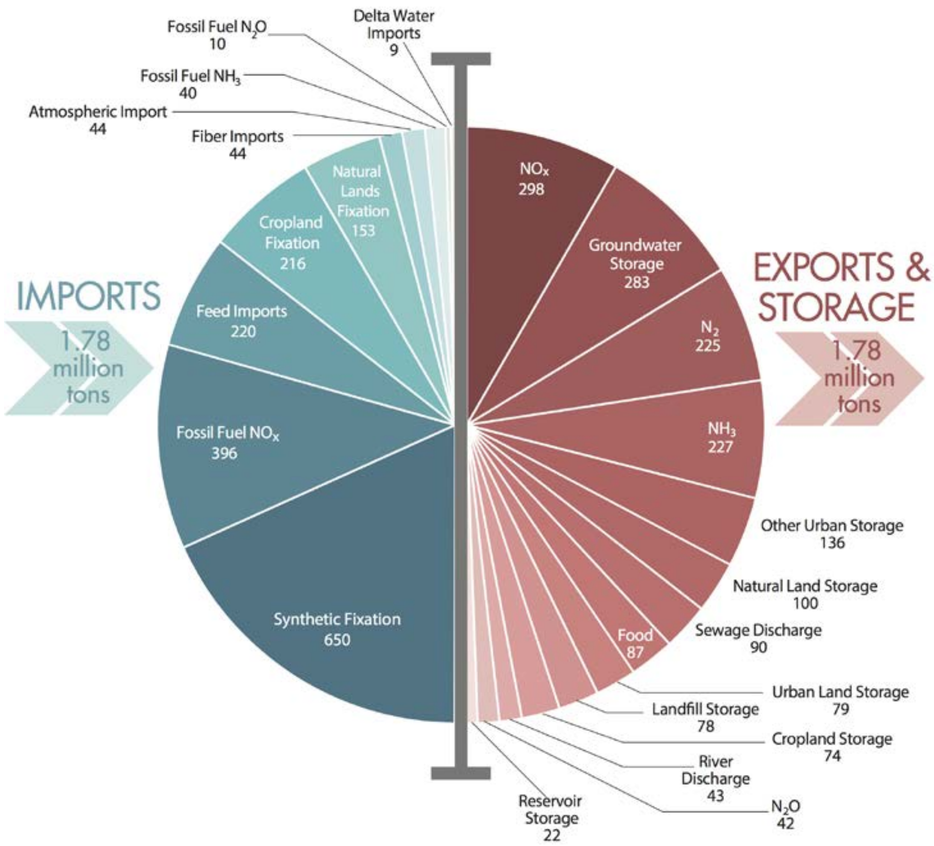
A key part of the CNA is the mass balance—a comprehensive accounting of nitrogen inputs and outputs for California per year (2005 is the focal year). This scientifically-rigorous accounting method tracks the size of nitrogen flows, which allows us to understand which sectors are the major users of nitrogen and which contribute most to nitrogen leakages to the air, water, and ecosystems of California.

The CNA began as an attempt to learn the role of nitrogen in climate change. Ultimately, the mass balance revealed that, by weight, nitrogen's contribution to groundwater nitrogen is significantly greater than its contribution to greenhouse gas emissions.

Annually, nearly 1.8 million tons of nitrogen are imported into California through a variety of sources.

Agriculture is the largest source of nitrogen in California. **Synthetic fertilizer accounts for 32% (514,000 tons) new nitrogen entering CA each year, and animal feed accounts for another 12% (220,000 tons).** Synthetic fertilizer applied to fields is partially taken up by the crop: on average, about half the nitrogen applied to crops is lost to the environment, though this varies greatly by soil type, crop, and farm management practices.

Fossil fuel combustion is the major (40%) source of nitrogen to the atmosphere, with nitrogen oxides (NOX) as the predominant (89%) form of fossil fuel emissions. 30% of nitrogen losses are transported downwind from California as NOX or ammonia (NH3), making California a major source of atmospheric nitrogen pollution. Ammonia is a component of fine particles PM2.5 and PM10, which have well-established health impacts. Nitrogen oxides are precursors to ozone.



Annually, nearly 419,000 tons of nitrogen leach into groundwater. **Nitrogen from cropland (including fertilizer and manure applications) is the largest contributor, accounting for 88% (367,000 tons) of nitrogen leaching to groundwater.** Only a little over a third of the net annual nitrogen inputs to groundwater are extracted from wells for irrigation and drinking water or removed by denitrification in the aquifer, leaving two thirds of the additions each year to accumulate in groundwater. However, it can take years to millennia for excess nitrogen in soil to reach groundwater.

Livestock consume 614,000 tons of nitrogen each year in their feed. Only 25% of that becomes meat or milk for our consumption; the rest is excreted in manure. Much of that manure is reapplied to cropland, where its nitrogen has the potential to leach into groundwater. Some of the nitrogen in manure is released into the air or water or stored in soils.

Nitrous oxide (N_2O, a potent greenhouse gas) accounts for 4% of greenhouse gas emissions in California. Agriculture, by way of cropland soils and manure management, accounts for 32% of those N_2O emissions (1.3% of total statewide GHG emissions). However, these estimates are based on California's Greenhouse Gas Emissions Inventory methodology, which uses general global emissions factors that do not account for California-specific conditions.

61% of wastewater is discharged into the Pacific Ocean (about 90,000 tons of nitrogen). Only a small amount (about 13,000 tons) of wastewater nitrogen was discharged into surface water bodies of California. Discharge of treated wastewater to land (about 12,000 tons) that subsequently leaches to groundwater was a small (9%) fraction of wastewater. About 24,000 tons of biosolids are applied to cropland and placed in landfills. Very small amounts of N_2O are released during wastewater treatment processes.

Nitrogen Impacts on Human Health

Air

Nitrogen is a component of, or aids in the formation of, five known air pollutants including nitrogen oxides (NOX , which includes NO2, nitrogen dioxide), ammonia (NH3), ozone (O3), and particulate matter (PM2.5 and PM10). Major emissions sources include the combustion of fossil fuels in the transportation, energy generation, and industrial sectors, as well as agricultural fertilizers and livestock.

Despite significant declines in nitrogen oxides, ozone, and particulate matter over the past four decades, much of California's air quality still fails to meet one or more state recommendations set to protect human health.

This comes at great health and economic cost. The California Air Resources Board estimates that annual exposure to PM2.5 results in 7,300 excess deaths from cardiopulmonary diseases and 5,500 from heart disease. Health costs attributed to ozone levels that exceed California's recommendation include an estimated 630 deaths, 4,200 hospital admissions for respiratory disease, 660 ER visits for asthma, and 4.7 million days of missed school among children. Residential segregation by race in some parts of the state has been shown to result in disproportionately higher rates of exposure to ozone and PM2.5 of Hispanic and Black residents compared to White residents.

Water

Relatively low concentrations of nitrite and nitrate are found in drinking water from the state's surface water. In contrast, nitrate levels in groundwater have increased over the past several decades, and some parts of the state now exceed federal standards for safe drinking water.

People in agricultural areas, particularly those with domestic wells, are more likely to be exposed to high levels of nitrate in their drinking water than those in urban and suburban areas. Groundwater from some wells in the Tulare Lake Basin and Salinas Valley (major agricultural regions) regularly exceed state and federal standards. Between 212,000 and 250,000 people in these areas, or approximately 8.0%–9.4% of residents, are highly susceptible to exposure to nitrate in the drinking water that exceeds the state maximum level. A disproportionate number of these residents are of Latino ethnicity and are considered low-income.

That elevated nitrate consumption can have significant impacts on human health is clear; however, further research is needed to clarify uncertainties about the exact physiological impacts of different levels and types of nitrate exposure. It can take from several years to millennia for nitrogen leached from the soil surface to enter groundwater, so groundwater contamination will likely continue to mount for the foreseeable future.

Technological Options to Minimize Nitrogen's Negative Effect

Moving forward, Californians can work together to adapt systems to maintain productivity, minimize exposure, and relieve further pressure on the environment. Adaptation will be especially important as populations, and concentrations of reactive nitrogen in the environment, grow. Improvement of agricultural, industrial, and transportation nitrogen efficiency offers a rare win-win opportunity to advance economic and environmental goals.

We have identified nine control points where changes could improve nitrogen efficiency and reduce nitrogen losses, and identified the priority areas that could bring about the greatest reductions. Those priority areas include:

Agricultural Nitrogen Use Efficiency and Cropland Management

Our estimates suggest that gains in efficiency could result in nearly 40,000 tons less fertilizer nitrogen use per year and 90,000 tons less feed nitrogen demand per year with greater adoption of soil management practices. Using the mass balance developed for the CNA, we determined that stopping groundwater nitrate accumulation would require a 67% decrease in current leaching (283,000 tons), a significantly larger decrease than appears to be feasible just by using current technology to improve nitrogen use efficiency. Future efforts to increase nitrogen use efficiency will have to go beyond the development of new technological innovations to address socio-economic drivers of technology adoption and use.

Energy and Transportation Sector Efficiency

California has led the nation in combatting emissions, primarily of nitrogen oxides, but decreasing emissions further remains critical. It is generally accepted that decreasing total fuel combustion will be key to major reductions in GHG emissions and other nitrogen-based pollutants. Alternative fuel and alternative vehicles offer promising pathways to improvement, but are complicated by upstream emissions from power generation.

Manure Management

In Central Valley dairies, 25%–50% of nitrogen in excreted manure is lost as ammonia emissions. That wide range indicates room for improvement for operators with the highest emission rates. Reducing ammonia emission requires a whole farm approach, since decreasing pollutants in one point of the manure management train serves to conserve nitrogen in the manure, which may then result in increasing emissions at a later point.

Wastewater Management

Wastewater nitrogen management could be transformed to expand nitrogen removal where appropriate and stimulate recycling whenever possible. Technologies available include creating conditions to support microbial nitrification and denitrification (with nitrogen released harmlessly into the atmosphere as non-reactive N_2) and separation of solid and liquid portions of the waste stream for reuse as fertilizers.

Consumer Choices and Food Waste

Demand by U.S. and global consumers shapes farmers’ decisions on what crops to produce and how to produce them. Because foods differ in their nitrogen content and requirements, consumer preferences for specific commodities can have a large influence on local, statewide, national, and global nitrogen cycling. In California, food waste accounts for 24% of landfill materials. Finding ways to reduce waste would reduce the nitrogen load in landfills and recycle food-nitrogen to the soil.

Policy Options to Minimize Nitrogen's Negative Effect

Any successful strategy to reduce nitrogen emissions from agriculture must take a comprehensive approach to the most important forms of nitrogen leakage into the environment—particularly ammonia and nitrate, but also including nitrous oxide—to avoid "solving" one nitrogen problem while worsening others.

Design of policies should consider relationships between nitrogen sources and their specific impacts and how these may be both spatially and temporally distributed. A suite of policies may be needed to achieve both adequate source control and mitigation of the existing stock of nitrogen, at the appropriate local to regional spatial scale and within reasonable timeframes.

From among the categories of education, standards, and economic incentives, potential policy instruments were assessed for two high-priority nitrogen issues: nitrate emissions to groundwater and ammonia emissions to the atmosphere.

For each, six criteria were systematically applied to assess potential policy instruments based on available evidence. The six criteria are adaptability, institutional compatibility, distributional effects, cost effectiveness, technological feasibility, and environmental effectiveness.

The policy instruments that rated highly across all six criteria for these pollutants fall within the categories of **standards and economic incentives**. Although they are not typically effective alone, education-based instruments can play a supporting role to other policy mechanisms.

With current technology, certain practices and technologies could reduce the amount of reactive nitrogen in the environment. Producers are increasingly able to implement the 4Rs of nutrient stewardship in crop production: right amount, right time, right place, and right form. Overall, however, voluntary implementation is low because technologies and practices that can reduce nitrogen pollution typically are costly for farmers and ranchers and potentially involve other factors such as lower yields, perceived risks to production, and lack of adequate scientific information to support the many specialty crops in California.

Even if policies somehow could perfectly control nitrate leakages from farms and dairies starting immediately, California will be living with the consequences of past nitrate leakages for decades to come.

Thus, for communities where drinking water supplies are unsafe because of high nitrate concentrations, point-of-use treatment or other short-term solutions are needed in combination with lasting safe drinking water solutions.

Nitrogen solution scenarios

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The emissions of reactive nitrogen (N) has multiple and widespread consequences for ecosystems, climate and human health. There are also multiple sources of reactive N. However, in a country like Denmark, where agriculture occupies more than 60% of the land area and where intensive livestock production is one of the main agricultural activities; the agricultural sources of reactive N dominate the picture. Over recent decades, considerable effort in technologies and regulation has been undertaken to reduce the reactive N emissions from agriculture. There has in particular been focus on reducing ammonia volatilization and nitrate leaching.

Both global and national drivers and trends may be expected to lead to major changes in N cycling in Denmark through effects on land use and management as well as changes in the internal and external cycling (and losses) of nitrogen in farming (and societal) systems. These drivers can be divided into four major categories:
- Changes in demand for biomass products (food, feed, fiber and bioenergy)
- Changes in technology, in particular within agricultural land use and management
- Changes in priority of land for other ecosystem services
- Changes in environmental conditions (including climate change).

Some of these drivers are in practice interacting. Thus, several of the drivers are to some extent caused by an increasing global human consumption caused by a rapidly growing global middle class. This change in consumption also leads to emissions of greenhouse gases causing climate change, which in turn affects the regional and local suitability for agricultural and biomass production as well as the susceptibility of natural ecosystems to external inputs such as nitrogen and phosphorus loading from agriculture. This may in turn affect policies for protecting the natural environment, also affected by local priorities for clean and healthy environments.

Three different groups of solution (mitigation) scenarios have been explored in the DNMARK research alliance
- New production chains with more efficient use and recycling of N
- Geographically differentiated N-mitigation measures based on planning and management of agricultural landscapes
- Changed consumption patterns driving land use change and reducing N use.

These solution scenarios are evaluated in terms of how they can contribute to and ideally comply with targets agreed for nitrogen pollution to surface and groundwater (Water Framework Directive; Nitrates Directive), ammonia volatilisation (CAFE) and nitrous oxide (EU climate targets). In addition the scenarios may depend on their internal logics and the measures adopted lead to other benefits in terms of effects on biodiversity, nature and ecosystems as well as different types of productions giving various types of revenue. In practice it is often difficult to estimate the extent of measures that will lead to required emission reductions. We have therefore mostly chosen specific extents of measures and evaluated the results in terms of losses of reactive N from the agricultural activities.

New production chains with more efficient use and recycling of N

These measures are based on technologies that aim at enhancing the N use efficiency or mitigating specific loss pathways. There are many possible technology routes that can be applied. In this study three different possible technologies were identified for assessment at the national scale:

- Anaerobic digestion (biogas) of livestock manure. This will enhance the utilization efficiency of N applied in the field, but may also increase ammonia volatilization. Overall this reduces the need for use of mineral N fertilizer and also N leaching.
- Acidification of livestock slurry (cattle and all). This will substantially reduce ammonia volatilization, which enhances the content of mineral N in the manure applied in the field. This may reduce the need for use of mineral N fertilizer. This will not in itself reduce N leaching, but if combined with use of nitrification inhibitors there may in some cropping systems and soil types be a possibility to reduce N leaching during spring time (in particular for N applied to silage maize and potato).
- Green biorefining. Denmark has a high import of soybean for supplying proteins to the intensive livestock production (in particular pigs and poultry). In this scenario proteins are produced from grassland (intensively fertilized grass and grass-clover) to substitute the current import of soybean. This will enhance the area with grassland, which in general has a lower N leaching than typical cereal-based cropping systems, which dominate the Danish landscape.

Geographically differentiated N-measures based on planning and management of agricultural landscapes

The focus of geographically differentiated N mitigation measures relate to the different susceptibilities of aquatic ecosystems (groundwater, fresh water and marine systems) to N loading across the landscape and to differences in the capacity of landscape components to reduce nitrate to N_2 (groundwater and surface water). The possibilities of applying differentiated N-measures depend highly on the scale at which these are applies, since both vulnerability and N reduction varies greatly across the landscape. In this study the focus was on applying measures (set-aside) for reducing N loadings to the marine environment in Denmark. The N-loading was calculated from the N leaching from the root zone corrected for N reducing in groundwater and surface waters. The effect was assessed by evaluating the area needed to comply with the Water Framework Directive targets for maximum load to individual marine environments. Three different criteria for targeting the placement of set-aside were evaluated: N reduction in groundwater and surface waters, naturalness (biodiversity) of the landscape, and land value.

Changed consumption patterns driving land use change and reducing N use

Changes in both local and global consumption (and production) patterns will affect N use and N losses in Danish agriculture. For this two alternative food demand scenarios have been considered, which are likely to have an impact on agricultural production, land use and nitrogen balances in Denmark: 1) Changed global consumption scenario, and 2) Local consumption scenario. The first consumption scenario represents a change in the export demand for Danish agricultural products (including the extent to which production to the domestic market will have to adapt to a changed export demand), whereas the second scenario represents a change in the domestic food demand behavior and the resulting changes in exports that may follow from this change, given the total area available for agricultural production. Both scenarios are compared with a baseline, which corresponds to the observed situation in 2010. The agricultural activities in these scenarios are estimated based on an economic model. The scenarios are defined as follows:

- Global consumption. In this scenario Denmark is a world leading agricultural nation, with a highly intensive agricultural production. The livestock and crop production is intensified with all the technology available, to improve productivity and reduce the environmental and nitrogen impact as much as possible. The land use is intensified both for production of grass for protein and energy in biogas plants and biorefineries, and intensified for production of corn and straw for feed to the livestock.
- Local consumption. In this scenario, domestic consumer demand drives a shift away from intensive agricultural production towards extensive agricultural production. The agricultural production is based on high quality products, where half of the meat production comes from livestock grazing on nature areas. Consumption of low input products (e.g. dairy products, New Nordic Diet foods, regional vegetables and fruits etc.) is increasing both in local consumption, and especially in the gastronomic industry and marketing to tourists. There is a growth in consumption of special regional brands, such as products from local areas as Lammefjorden and Vildmose. In the larger cities and their surroundings, local food companies organize projects with urban gardens, school gardens, beehives, pet cows, etc., all of which are actively used for social integration and stress treatment (i.e., social farming, urban farming, care farming etc.). A more close relationship between consumers, retailers and institutions is established. A local protein supply (especially for fodder) is established. An increase in the demitarian diet, with the basic, recommended protein supply results in an increase in demand for umami-rich meat substitutes. The resultant cost of the increase in domestic demand for quality meat will also cause a decrease in quantity.

Two additional scenarios are considered that are also related to consumption:

- A 50 % reduction in livestock production. This is expected to be driven by a local and global consumer trend towards less consumption of meat and dairy products. This is assumed only to affect the production of livestock manure and reducing this by 50%.
- A conversion of all agricultural production to organic farming. The current proportion of area in various farming systems (arable, cattle, pig) are maintained. This will lead to an overall reduction in livestock production, no use of mineral fertilizer and a reduction in import of protein feed (soybean).

Current water quality ambitions in many Dutch regions incompatible with intensive agriculture

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Dutch manure and fertilizer policy stabilizes manure problem but challenges remain

The Manure and Fertilizers Act (M&F Act; Meststoffenwet) is, in part, the Dutch implementation of the Nitrates Directive. The M&F Act determines, inter alia, how much nitrogen and phosphates, through synthetic fertilizers and animal manure may be used on grassland and arable land, and how these may be applied. In 2006 the Dutch system of nitrogen and phosphate application standards replaced the MINAS system (1998-2005), which was based on maximum surpluses of nitrogen and phosphate. Since 2006 environmental quality further improved and on average, the target of a maximum of 50 milligrams of nitrate per liter in groundwater is met almost everywhere. Only in the southern sand region the average nitrate concentration in the upper groundwater still exceeds the target. But solution of the eutrophication problem in regional surface waters strongly influenced by agriculture is not yet in sight; there nitrogen and phosphorus targets are still substantially exceeded. Another aspect of the manure problem is the pressure on the manure market; which remains high. Due to the large livestock population, in combination with stricter application standards, currently about half of the produced phosphate in manure must be disposed of by the livestock farms, of which half outside the Dutch agriculture.

Nitrate target almost met, but exceedance in the southern sand region persists

An important objective of the Nitrates Directive has almost been achieved: in the period 2011-2014 exceedance of the nitrate target in the upper groundwater of the sand region on average was less than 5 milligrams per liter. Nitrate concentrations between 2006 and 2014 decreased, but less than in the period before 2006. Model analysis reveals that this decrease mainly is a delayed result of measures in the period before 2006 and caused by slowly declining mineralization of soil nitrogen. Exceedance in the southern sand region was 30 milligrams of nitrate per liter and therefore substantial. A considerable part of the current exceedance could be the result of manure fraud. Indications for this fraud are exceedance of the legal space to apply animal manure, as inferred from regional manure accounting, surveillance results showing that on approximately 10 percent of so-called “high risk” farms one or more of the legal application standards are exceeded, and the frequent occurrence of unlikely high phosphate levels in samples from transported manure. Models predict that an exceedance of 10 milligrams of nitrate per liter will persist in the southern sand region in 2027, despite the introduction of lower nitrogen application standards in 2014. The model analysis reveals that the potential decrease of nitrate leaching is largely offset by an increase in the use of nitrogen-rich manure separation products. This allows farms to use more nitrogen from animal manure within the legal application limits without exceeding the phosphate application standards.

Current implementation of Manure and Fertilizer Act barely reduces eutrophication in 2027 as required for the WFD

One of the objectives of the Nitrates Directive is to reduce eutrophication of surface waters. The M&F Act does not contain explicit eutrophication target; these targets are part of the implementation of the Water Framework Directive (WFD) to support attainment of a good aquatic ecology in 2027. In the period 2011-

2014, these eutrophication targets for phosphorus and nitrogen were exceeded in about half of the surface water monitoring sites predominantly influenced by farmland. If agriculture related sources should deliver a proportional contribution to meet these targets relative to other sources, the national agricultural load of phosphorus should decrease by approximately 40 percent and of nitrogen by about 20 percent. With the current implementation of the M&F Act, in 2027 approximately one-third of this WFD-task for nitrogen is realized and approximately 10 percent for phosphorus. The M&F Act therefore provides a modest contribution to achievement of the eutrophication targets as defined in the Nitrates Directive (prevention and reduction) and the WFD (in 2027).

Around 2015 the current M&F Act has ended the soil accumulation of phosphate in the agricultural area. Achieving a national balance between phosphate input and output was a target of the M&F Act set in 1995 for the year 2000. Stricter phosphate application standards since 2010 for the so-called phosphate-saturated soil, result in phosphate mining in grassland at a rate of more than five kilograms per hectare per year. Nevertheless, model analysis indicates that a decrease of phosphate soil stock unlikely will contribute to improved surface water quality before 2027.

Current policy approach offers few prospects for solution of manure problem

The nutrient loading of surface water can be reduced by measures to reduce the soil nutrient surpluses. Reducing use of manure and synthetic fertilizer by further tightening of the application standards would be most effective. From an agronomic perspective, however, there is little room for tightening the nitrogen application standards, because these are now already at or just below the level of the fertilizer recommendations. For phosphate, there may be scope for tightening standards within the agronomic recommendations. As the use of synthetic phosphate fertilizer is already low on arable land and almost absent on grassland, tighter legal standards automatically mean less room for the use of animal manure. This almost leads directly to higher costs for manure disposal for livestock farms and possibly to less revenues for arable farmers (and extensive livestock farmers) when accepting manure. Therefore, measures that prevent nutrients to reach surface water are more favorable, such as measures that prevent surface runoff of nutrients and measures to improve soil structure. A barrier for farmers to take many of these measures is that they lead, on short-term, to additional cost or labor. Over the past decade, the annual costs for the disposal of manure for the livestock sector are fairly stable and lie between 250 and 300 million euro. The manure disposal costs per livestock farm tend to increase in the pig and dairy business, but this is mainly due to the autonomous expansion of farms. For an average pig farm these costs amount to 40,000 euros per year, and represent about 5 percent of total production costs. Many farmers express concerns that further tightening of application standards leads to reduced crop yields and soil fertility. While these concerns are not supported by available measurements, they add, together with increasing manure disposal costs, to a decreasing support among farmers for the M&F Act.

Limiting livestock remains necessary

In general, a smaller livestock will reduce pressure on the environment and the manure market. However, many livestock farms strive to expand in order to increase economic efficiency and farm income. In the M&F Act the pigs and poultry livestock are capped since around 2000 by a system of tradable manure production quota. These quota are fully utilized, and in some regions available quota are exceeded by tens of percent. Indirectly, livestock is also limited by the statutory limits to apply manure. To achieve targets for emissions of ammonia and greenhouse gases, and water quality targets, it is therefore important to maintain the quota system for pigs and poultry. In addition, phosphate production quota will be introduced for dairy in 2018 to reinstall control of manure production after the abolishment of the milk quota system in 2015. In 2017 measures are taken to reduce the dairy stock and the associated manure production to comply with derogation conditions. The use of low phosphate feed also contributes to a reduction of the current pressure on the manure market.

Increasing dependency on manure export renders the livestock sector vulnerable

A decreasing amount of manure can be disposed of onto Dutch agriculture land in view of the gradual tightening of the phosphate application standards. This leads to an unrelenting pressure on the fertilizer market: the costs for disposal of manure remain high and the dependence on export of manure and manure products increases. The introduction of mandatory manure processing has boosted the processing industry but has not reduced pressure on the manure market or disposal costs per ton of manure. In particular, the exports of unprocessed, sometimes unpasteurized, manure products is not future-proof. There is a risk of export of pathogens, and Germany, the main importer of Dutch manure is in the process of revising and tightening its manure policy. This makes the future of animal husbandry vulnerable and, in particular, the pig business, because of their high share in manure exports.

Society benefits from stricter manure policy

The societal benefits of the M&F Act are considerable. However, quantification and monetization of those benefits is uncertain. Total annual benefits of the M&F Act in 2008 as compared to the year 2000 were estimated at 0.4 to 2.5 billion euros per year. The annual benefits for ecosystems were 0.3 to 2 billion euros, and a result of reduced leaching and run-off of nitrogen and reduced ammonia emissions and deposition. The benefits for human health are in the range of 0.1 to 0.3 billion euros and due to reduced ambient levels of ammonia aerosols, and, to a much smaller extent, by reduced nitrate in drinking water. The major costs are for manure disposal and storage and in 2008 amounted to approximately 0.4 billion euro a year, and did not significantly change since the year 2000. On a national level this represent no net cost but a financial transfer form (intensive) livestock farming to farms accepting manure and entrepreneurs transporting and storing manure. However, there is a net public cost of about 30 million euro for administration and compliance of the M&F Act. Both the net and gross costs are lower than the lower bound of the societal benefits which indicates that stricter manure policies will also provide net benefits for society. But a question is whether farmers should bear additional future costs for cleaner water when they fertilize according to agronomic recommendation and comply with legal rules. In recent years the tension has increased between, on the one hand, the legal application standards and rules for the use of fertilizers, and, on the other hand, conventional crop rotations and associated fertilization recommendation. Especially in the sand region arable farmers are not always allowed to apply recommended levels of nitrogen fertilizers. This is one reason that agricultural entrepreneurs are losing faith in the government and in the merits of the M&F Act. There is dwindling understanding for the water quality objectives and for compulsory measures. Also, farmers consider the policy too complex and too costly. This attitude can compromise the compliance and effectiveness of the M&F Act.

Current approach to tackle manure problem has reached its limits

The current regulatory and generic approach in the M&F Act seems adequate to achieve the nitrate target for groundwater. However, it lacks the ability to deliver custom solutions to achieve nutrient targets for the WFD in regional surface waters in large parts of the Netherlands. The nitrate target could be met, especially when the national and regional authorities, the agricultural sector and the affiliated agro-industry work together to tackle the issue of manure fraud. However, the current conventional agricultural and fertilizer practices, although in accordance with agronomic recommendation, and economically optimal crop choices, will not lead to achievement of nutrient targets for the WFD in regional surface waters, especially in the southern sand region and the central clay and peat region. The M&F Act does not provide positive incentives for farmers to change fertilizer practices. A first step for the authorities to improve farm support and the credibility of M&F Act is to re-invest in communication of targets and measures in this Act and its relationship with targets in Nitrate directive and the WFD.

Regionally customized solution offers more perspective to meet nutrients objectives of the WFD

A more regional approach offers a better perspective to meet targets of the Nitrates Directive and the WFD and links closely with implementation of the WFD by river basin management plans. In so-called regional arrangements, farmers, (agro) industry, water managers, governments, nature conservation organizations, NGOs and inhabitants work together to find economically achievable and accountable targets and packages of measures while integrating goals for water quality with those for other policies (such as nature and climate). By this, there is more scope for development of local custom solutions, where farmers and other stakeholders share knowledge and create synergy advantages. Achievement of targets is improved while negative side effects for farming in the catchment can be reduced by improved coordination of land use, crop choice, fertilizer and manure application and intensity between farms, and by improved linkage to local ecosystem sensitivity within a sub catchment. Currently, farms are individually accountable for proper implementation of the M&F Act. The proposed regional approach would require experiments with new (legal) instruments to equalize local exceedances of environmental goals and cost of measures or loss of yields between farms. Coordination of this regional process by national and regional authorities remains necessary to secure that regional environmental targets are met and problems are not passed on to neighboring regions. Moreover, the government is accountable to the European Commission for implementation of common EU directives. Although regionally customized solutions offer more perspective to achieve the targets, in some regions the WFD objectives are not reconcilable with the current conventional agricultural economy. The question is whether and at what cost these objectives should be achieved everywhere, or whether new forms of less productive, extensive forms of agriculture have potential and can be subsidized or financially compensated.

This abstract is a translation of the Summary of the formal evaluation of the Dutch M&F Act as published in March 2017 (http://www.pbl.nl/publicaties/evaluatie-meststoffenwet-2016-syntheserapport).

Targeted regulation: A framework for Nitrogen Regulation. Cost-effectiveness, spatial distribution and policy trade-offs

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Targeted regulation is a framework for environmental regulation when the outcome of measures to abate pollution is heterogeneous in space and the sensitivity of recipients vary, so that the optimal abatement differs between catchments. Spatial differentiation might lead to more cost-effective abatement compared to general regulation, but might also lead to distortions in the distribution between farmers and regions, that might be politically undesirable. Differentiation and targeting abatement in agriculture to obtain one objective, such as good ecological status (GES), might result in negative or positive trade-offs with other policy objectives. Examples are trade-offs between nitrogen load reduction to freshwater recipients (including groundwater) and coastal water, and tradeoffs between carbon sequestration and nitrogen load reductions. Another strand of research is that there also might be conflicts between targeted policies to obtain GES and nitrogen resource efficiency. In the dNmark alliance and related projects we have developed spatial economic model frameworks to analyse such trade-offs.

In the presentation we demonstrate how such models can be used to assess how hydreogeological mapping assumptions influence the cost-effective differentiation of abatement within catchments, the trade-offs between different policy objectives and ecosystem services, (e.g. nitrogen reduction, carbon sequestration and GHG emission reduction), and tradeoffs between nitrogen efficiency and targeting to achieve GES. We highlight spatially explicit economic land use and abatement technology allocation models, as useful conceptualisations of policy trade-offs.

Nitrogen and Health

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Danish farming is among the most intensive in the world, and intensive livestock farming and extensive use of nitrogen (N) fertilization causes severe N losses to soil, surface water, groundwater and air. Danish drinking water supply relies on simple treated groundwater, and protection of groundwater is therefore having a high priority for public health.

Studies on air pollution in Denmark have shown, that contributions from Danish farming related emission to the total health-related external costs of air pollution in Denmark amounted to 33% in 2008. These estimates are based on the contribution from agricultural emissions to the formatting of fine fraction particles; where the latter is currently believed to be the most important contributor to health effects. Whether agricultural nitrogen may have a specific health effect has to our knowledge not previously been explored. The particles produced in the air are an effect of ammonia emissions from farming operations, either by direct evaporation from the farms, or by evaporation during the infusion of manure into the fields as a fertilizer. Nitric acid (HNO_3) is present in the atmosphere from combustion sources. When NH_3 is emitted, it reacts with HNO_3 to form particulate ammoniumnitrate (NH_4NO_3) and thereby contributing to fine fraction particle mass ($PM_{2.5}$). Both NH_3 and HNO_3 deposits very fast compared to NH_4NO_3. NH_4NO_3 may be released back as gas phase NH_3 and HNO_3. The balance between the gas phase compounds depends on atmospheric temperature and humidity – a so-called deliquescence point. NH_4NO_3 serves thus as a reservoir of the two gases. All three compounds are efficiently removed from the atmosphere during rain events (even at short showers). When deposited no matter whether this is by dry or wet deposition all three nitrogen compounds may contribute to nitrate in ground waters.

Concerning drinking water, approximately 1.3% of the Danish consumers received water with nitrate concentrations above the drinking water standard of 50 mg/L in 2012. Private wells in rural areas serving a few households often abstract near-surface groundwater with higher concentrations of nitrate than public waterworks. The public waterworks utilize the deeper ground water reservoirs with lower concentrations of nitrate. It is estimated that in 2012 2.5% of the Danish population receive drinking water from public waterworks that contain nitrate concentrations higher than 25 mg/L. The prevalence of such high exposures is more frequent for Danes living in intensive agricultural areas with nitrate vulnerable aquifers (e.g. 16% in North Jutland) and in households using private wells (37 % in average for whole Denmark).

Health effects of nitrate are diverse, and range from “blue baby syndrome” observed in children fed on formula in US in the 50ties, a concept that today is challenged, as it seems that nitrate is not the only prerequisite for this syndrome. The conversion of nitrate to nitrite causing the adverse effects is depending on bacterial contamination of the well water. During recent decades colon cancer and childhood cancers of the lymphatic and the central nervous system have been found associated to increased nitrate concentrations in drinking water, although the evidence is not unequivocal.

The present talk will review the possible adverse effects of reactive N-forms in air and nitrate in drinking water. Finally the public health consequences and future research needs will be discussed.

Nitrogen Europe's agri-food system and its consequences on environment and human health

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Food production and dietary patterns are increasingly wasteful, characterized by health inequality, and cause huge environmental costs. Achieving a trend reversal is one of the big challenges of the 21st century and requires the integration of environmental protection, human health, and food security in a future agri-food system. The wasteful dietary patterns in the EU agri-food system create high nitrogen losses, resulting in considerable impacts on climate change, air quality, water quality, soil quality and biodiversity[1]. At the same time, diets are characterized by low nutritional value and lead to an increasing burden of chronic diseases in the European Region[2]. A reduction in animal protein, but also in innutritious "empty" calories offers potential to optimize diets in respect to both nutrition and environmental criteria. Application of mitigation technologies and implementation of good farming practice can help improving the nitrogen use efficiency of the whole agri-food system. On the other hand, nitrogen mitigation target cannot be reached without dietary changes towards plant-based option, alternative foods and reduced food waste[3].

We will review current literature linking policy interventions on sustainable diets (such as reviewed by [5]) and dietary choices (e.g. current diet, vegetarian diet, vegan diet) with the environmental consequences linked to losses of reactive nitrogen these diets cause. The presentation will frame some overarching questions relating the agri-food system with the nitrogen cycle, i.e. (i) How far can losses be reduced by technological options and how much emission reductions need to come from behavioural changes? (ii) What is the role of waste reduction? (iii) What are the direct (via nutrition) and indirect (via pollution) health effect of diets? These questions will be assessed more in detail in an upcoming report by the Expert Panel on Nitrogen and Food (EPNF) under the Task Force on Reactive Nitrogen, UN-ECE Convention on Long Range Transboundary Pollution (CLRTAP) [4,2].

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Nitrogen fluxes, impacts and boundaries at global and regional scale

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Background and aims

The intensification of agriculture in large parts of the world, including large inputs of nitrogen (N) to soil by fertilizers and manure, has led to an increase in crop growth but also to adverse effects on the environment. In some regions, especially in parts of Europe, US and China, high nitrogen inputs have led to: (i) loss of terrestrial biodiversity due to increased emission and deposition of ammonia (NH_3), (ii) eutrophication of surface waters due to increased N runoff and (iii) increased nitrate (NO_3) levels in drinking water reservoirs due to elevated NO_3 leaching. Inversely, in other regions there is still room for increasing N inputs without exceeding critical thresholds for N losses. This study assesses critical N inputs to agriculture at global scale and within EU27 and compares these critical inputs to current inputs.

Methods

The derivation of a critical N input in view of adverse environmental impacts, consisted of three consecutive steps, i.e.: (i) identification of critical values for defined N indicators, (ii) back-calculation of critical N losses to surface water or air that correspond to critical values for N indicators and (iii) back-calculation of critical N inputs from critical N losses. For the global-scale assessment we used results from the IMAGE and TM5 models, while the INTEGRATOR model was used to calculate current and critical nitrogen inputs at EU27 level. The calculated spatially explicit critical N inputs in view of losses to air and water were then compared with current N inputs (for the years 2000 and 2010) at the same spatial scale. For areas where critical N inputs were below current N inputs, we calculated at EU level the needed increase in nutrient use efficiency (NUE) to attain environmental objectives at current crop yields, since an enhanced NUE implies a lower needed N input and thus a lower fraction of N that is lost to the environment.

Results

At the global scale, total estimated critical N inputs in view of N runoff to surface waters or NH3 emissions to air were 35-50% lower than current (year 2000) N inputs, but this estimate is likely too high because of an underestimation of the critical N input . More detailed calculations at EU-27 level showed that the critical N inputs were approximately 20% lower than current (year 2010) N inputs, using either critical N concentration in surface water or critical N deposition as criterion. The calculated NUE values that are needed to attain the current crop yield while not exceeding critical environmental thresholds nearly always ranged between 50 and 90%.

Conclusions

At a large regional scale, the current N input is not much higher than the critical N input. However, there is a strong need for a spatial reallocation of the N inputs to N deficient regions and an increase in NUE in highly productive regions to avoid exceedances at regional scale.

Water quality policies at the crossroads between common targets and decentralized enforcement

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Nitrogen and phosphorus loads are considered a major reason for the eutrophication of inland, coastal and marine aquifers in the Baltic Sea countries. Over the last half century, natural science research has provided support for policy makers through improved knowledge about nutrient transports and the response of aquifers to reduced nutrient loadings. Meanwhile, research in economics has contributed with knowledge on policy instruments that could reduce environmental pressure on affected water bodies at least cost to society, hence saving resources for other environmental and societal aims. This work has included comparisons of the performance of regulations, environmental taxes and subsidies, and nutrient trading schemes with regard to environmental target achievement, costs to society under conditions of uncertainty, and distributional effects. Economists have also pointed to the risk for policy failure when multiple decision makers are involved in water quality policy decisions. Indeed, many countries, sectoral agencies, and governmental bodies at different levels are involved in the development and implementation of water quality policies in the Baltic Sea region. If these decision makers place their own interest before those of others, there is a risk that the targeted water quality improvements will not be reached. Hence, policy makers are challenged with the task to develop and implement appropriate policies, while simultaneously managing diverging interests and uncertainties about both natural processes and human behavior.

Against this background, we should ask how policy makers have chosen to act. Until now, most of the nutrient abatement in the Baltic Sea countries has been made at point sources, while the implementation of policies for nonpoint sources has not led to equally large emission reductions. It is therefore of particular interest to better understand how decisions on policies for agricultural nutrient abatement measures are taken and implemented.

We have studied how countries in the Baltic Sea countries have taken decisions on agricultural nutrient abatement measures with respect to goal setting, policy instrument choice, and the level of implementation. One can expect that such decisions are determined by environmental, technological, and economic characteristics of the abatement measure and by socio-economic characteristics of the country where it is implemented. Our results suggests that income levels, institutional capacity, and synergies in abatement and enforcement are important determinants of policies developed and their implementation. To support future policy development, research should address the issue of how large scale policies should manage varying effects of measures across measure type and location, and further investigate possible improvements of the policy implementation process.

Mitigating ammonia emissions in the absence of government policy, the Canadian experience

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Background and Aim

It is difficult in Canada to have a nationwide policy for mitigating ammonia emissions from farms since agriculture is mostly under provincial jurisdiction, and ammonia is not considered a major threat. The importance of staunching the biggest N leak from Canadian agriculture for improving farm N use efficiency is often overlooked. This presentation discusses some of the farm practices widely used in Canada, without influence of any government incentives or regulations, that help to mitigate ammonia emissions.

Methods

The data for this work was collected with national farm surveys of the major Canadian agricultural sectors: beef, pigs, dairy, poultry and crops. Some of the data was also obtained from official national statistics.

Results

Just over half the emissions in Canada are associated with production of food consumed domestically and the rest from production of exported food. The greatest emissions are from cattle and pig housing and the spreading of all animal manures and commercial fertilizers. Over half the nitrogen in Canadian agriculture comes from N fixation by rotational pulse crops and forage legumes; this greatly reduces consumption of commercial fertilizer and hence the ammonia that would be lost after application. About 80% of spring grains in Western Canada are precision-injected (side-banded) with urea fertilizer, greatly reducing ammonia emissions; the practice saves time, enhances phosphorous uptake and increases yields compared to broadcasting. This technology cannot be adapted to winter cereals and forages in eastern Canada. Also in western Canada, over 50% of the pig farmers use low emission slurry applicators in order to reduce nuisance odours and the risk of nutrient runoff, the major threat to regional lakes. Summer grazing has been used almost universally as a low cost method for raising calves and pregnant cows across Canada, but in recent years winter grazing has nearly doubled, saving farmers the costs of preserving and transporting feed and manure. Increased grazing is a proven method to conserve ammonia that would be emitted from housing, storages and land application of manure. Most pig and poultry farmers in Canada use multiphase feeding to reduce both feed costs and this practice helps to reduce excretion of urea and uric acid which are transformed to ammonia.

However, some beneficial practices may increase emissions, such as reduced tillage, which constrains manure incorporation. Implementing additional low-cost BATs could reduce ammonia emissions by 96 kt NH3 year^{-1} or 26% of present emissions, but this could require government intervention. It is important to collect data on farm practices to quantify the benefit of abatement measures and have dependable estimates of emissions.

Conclusion

In Canada, strategies for harm reduction by limiting emissions during critical times may be more practical than reducing total national emissions, especially where large reductions are needed to have an impact on air quality.

New approaches for improved food chain N use efficiency

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Crop and animal production systems respond to (i) changes in markets (food demand), (ii) developments in knowledge and (food processing) technology, (iii) governmental policies and (iv) changes in climate and human health and security. These driving forces greatly vary across the world. Changes in food demand and preferences are main drivers globally, while developments in knowledge and technology, and governmental policies have become important notably in (medium) high-income countries. Changes in climate, human health and security can play a dominant role in low-income countries, and in countries with large weather extremes.

Governmental policies have supported agricultural production in many countries, through facilitation of the build-up of good knowledge and physical infrastructure, through market and product support, and through subsidies on inputs (including fertilizers). The main arguments for governmental support are (i) hunger and health concerns (food security and food safety) for the domestic population, (ii) the low competitiveness and modernization capability of small-holder farms, and more recently (iii) the care for environment, landscape and rural development. The type of governmental interference strongly depends on the political priorities regarding nutritional security, export orientation of agricultural production, and environmental protection. Most support is given by the 49 OECD (high-income) countries, which accounted for about 88% of the global value added in agriculture in 2012-2014, and collectively transferred an annual average of USD 601 billion to agriculture. In addition, they spent an additional USD 135 billion on general, governmental services that support the overall functioning of the agricultural sector (OECD, 2015). The percentage of producer support varied from 0 to 60% of total farm receipts; the support to farmers was >50% in Norway, Switzerland, Korea, Japan, 20% in China, 15% in European Union, 10% in United States, 5% in Australia and 2% New Zealand, in 2012-2014. Governmental support measures have been larger for crop production than animal production. These support measures are under debate, because of unfair competition (OECD, 2015).

The aforementioned driving forces have greatly affected the structure, productivity and the environmental performance of agriculture, especially from the second half of the 20th century. Nutrient pollution problems appeared in countries with intensive agriculture, while nutrient depletion became more apparent in developing countries. Nutrient pollution problems have been addressed through nutrient management policies from the 1980s, and although great progress has been made in some countries, nutrient pollution problems are still there. Typically, nutrient management policies include a variable combination of (i) nutrient input limitation, (ii) emission mitigation and good agricultural practices, (iii) production limitation and quota, and (iv) spatial planning of land use. Typically also, the nutrient management policies are ‘add-on’s’, are in addition to the aforementioned governmental support measures, although some attempts have been made to integrate agricultural and environmental policies in, for example, the cross-compliance and greening regulations of the Common Agricultural Policy (CAP) in the European Union. There is debate about ‘the effectiveness of the integration of environmental policies in the CAP’, and there is debate about ‘to which degree nutrient management policies affect the aforementioned main driving forces of agriculture’. Integration of the single nitrogen emission mitigation policies have also been suggested as a step towards more effective nutrient management policies.

Integrated nitrogen management emphasizes the need to manage nitrogen (N) in an integrated manner. The notion that N needs to be managed in a comprehensive and integrated way follows from the understanding that reactive nitrogen (Nr) once formed is involved in a sequence of transfers, transformations and environmental effects, that the economic costs of emissions abatement are often high, and that the management of a single source and/or a single Nr species, especially agriculture, is not always efficient, and that nitrogen management also affects the cycling of other elements, including carbon (C), phosphorus (P) and sulphur (S). Fundamental arguments for using integrated approaches to N management follow also from the first and second law of thermodynamics. Basically, the first law implies that the element N can be transformed into different species, but it cannot be 'destroyed'. The second law of thermodynamics basically implies that N has the natural tendency 'to dissipate' into the environment.

Though there is scientifically sound underpinning for considering the management of the various N sources in a more holistic and integrated manner, there are also barriers and constraints for more integrated approaches, such as the compartmental and discipline oriented structure and organization of policy departments and science groups. There is also discussion about 'what and how to integrate?' The discussion is in part also confused by lack of clear and accepted definitions about the terms 'integrate' and 'management'. Integration is perceived as combining separate elements and aspects in an organized way, so that the constituent units function cooperatively. There are 5 different dimensions of integration in N management, namely: (i) vertical integration, (ii) horizontal integration, (iii) integration of other nutrient elements, (iv) integration of stakeholders' views, and (v) regional integration. All dimensions will be needed for effective integrated N management strategies, and for enhancing N use efficiency in the whole food chain. The driving forces of agriculture have not been addressed yet in integrated nutrient management strategies.

Changes in agriculture are most rapid in the rapid developing countries in the world, notably in Asia, Latin America and also Africa. These regions face a rapidly increasing food demand and changing markets, also through urbanization and a rapidly developing food processing – retail chain. Domestic agriculture responds through intensification, specialization, up-scaling and agglomeration of agricultural sectors, fuelled in part through governmental support and technology development, and without much governmental restrictions so far. As a result, similar nutrient pollution problems are created in intensive agricultural production systems in Asia, Latin America and Africa as the ones that led ultimately to the nutrient management policies in European Union countries in the 1980s. The support and intensification and specialization comes first, then the awareness of nutrient pollution and then the search for effective nutrient management policies that decrease nutrient losses to acceptable levels.

Implications and recommendations

Agriculture has four main common driving forces, but the effects of these greatly differ across the world. These forces together also contribute to nutrient pollution problems, but the cause-effect relationships are often neglected initially. Nutrient management policies are the response of governments to the nutrient pollution, but not so much to the driving forces of agricultural change. The four commonly applied strategies in nutrient management policies can be effective in itself, but the relative importance of the strategies should depend on the driving forces and changes in agriculture. Greater attention should be given to (i) spatial planning of land use, and (ii) production limitation and tradeable quota, in addition to (iii) nutrient input limitation, and (iv) emission mitigation and good agricultural practices, especially in rapidly developing countries in Asia, Latin America and Africa.

In European Union, further emphasis should be given to the integration of CAP, nutrient management policies and policies related to the circular economy. Payments through the cross compliance regulation and rural development programme could be used more effectively for the eradication of stubborn nutrient pollution problems. At the same time, single nutrient emission mitigation policies should be further integrated, as indicated above. Food chain actors must have a greater involvement in the enforcement of nutrient management policies, also by monitoring and presenting information about the N use efficiency and P-use efficiency in the food production sectors, the food processing industry as well as in the whole food chain. This requires also training of farmers, in part through farmers' discussion groups. Transferring and implementing improved knowledge and technology in practice requires concerted actions of a broad group of stakeholders, facilitated through targeted incentives from governments and society. At the same time, greater attention will be needed for demand-side measures, to provide well-balanced nutritious food, to minimize food related human health impacts, and to reduce food wastes and losses.

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The European Nitrogen Assessment 6 years after: What was the outcome and what are the future research challenges?

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Introduction

With the first European Nitrogen Assessment (ENA) published six years ago (Sutton et al., 2011), we here reflect on what it achieved and what are the emerging research challenges. We consider each in turn, reflecting on how the agenda for nitrogen research and policy application needs to be developed in future. The ideas that we summarize here especially reflect developments within the Task Force on Reactive Nitrogen (TFRN) of the UNECE Geneva Air Convention, which represents the primary policy home for the ENA, and within the International Nitrogen Initiative (INI) and its European Centre, which provide an overarching international scientific network.

Goal and approach of the European Nitrogen Assessment

In summary, the objectives of the ENA were set as follows: "*To review current scientific understanding of nitrogen sources, impacts and interactions across Europe, taking account of current policies and the economic costs and benefits, as a basis to inform the development of future policies at local to global scales.*" (Sutton et al., 2011). The ENA was thus firmly placed at the interface of scientific understanding and policy application. More than this, we recognize that the ENA was a process, where the very act of designing the approach with stakeholders, of convening successive workshops on different parts of the assessment, and of engaging with lead authors in refining their key messages, could be seen as gradually building integration across the nitrogen cycle while improving awareness and understanding between scientists and stakeholders coming from different perspectives.

For these reasons, the 2011 ENA can be considered as a key collaborative effort resulting in a better understanding and knowledge application on the nitrogen cycle in Europe. It focused on working towards more joined up solutions to maximize the co-benefits of particular actions and minimize possible trade-offs or unintended consequences. Achieving these aims involved integrating assessment of different sources of nitrogen in the environment: agriculture, transport and energy, as well as identifying solutions that can be implemented both by source sector stakeholders (farmers, business, industry) and by citizens (transport and food choices). At the same time it meant identifying and joining up the five key threats of nitrogen pollution in Europe, which were summarized in the acronym WAGES, referring to Water quality, Air quality, Greenhouse gas balance, Ecosystems and biodiversity and Soil quality.

This idea of the ENA as a joint learning process has been continued under the TFRN, through the preparation of the ENA Special Report on Nitrogen and Food "*Nitrogen on the Table*" (Westhoek et al. 2015). While a key aspect of the TFRN work programme, this work also constitutes a major scientific advance with high public relevance, thus it was agreed to be published as an "ENA Special Report".

This last point highlights another key aspect of the ENA: to use it as a vehicle to raise public awareness on the nitrogen challenge through the press, TV, radio and other media. A major effort was placed in communicating messages to the public through the ENA launch, including a special launch video (Howard and Sutton, 2011), a scientific conference and media briefing. A similar strategy was taken with the "Nitrogen on the Table" outcomes (Westhoek et al. 2014, 2015), including media briefing and an event at the European Parliament, contributing to increased press awareness. These actions are especially important, since one of the conclusions of the ENA 2011 had been that developing greater public awareness is one of the pre-conditions to overcoming the barriers to change for better nitrogen management.

Outcomes of the European Nitrogen Assessment

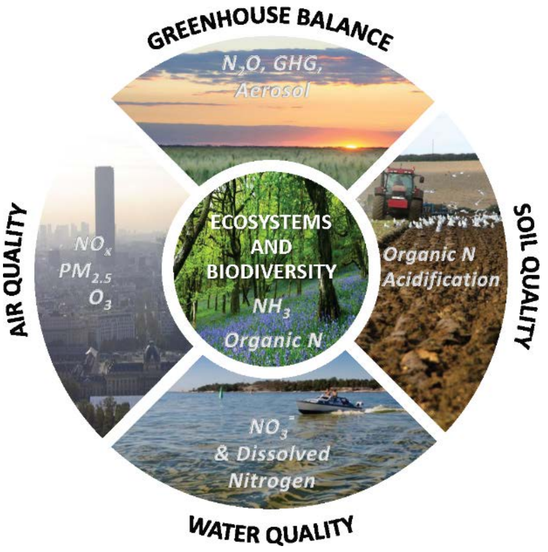
While increased press and public awareness are pivotal for increasing the impact of the ENA, it is important to reflect on what were the major substantive outcomes and how these have since developed. While it is surely impossible to list all the consequences we here draw attention to several key themes:

Nitrogen cycle perspective: The ENA has without doubt increased attention to the nitrogen cycle as a whole, building capability of the science community to link across traditional divides, such as between soil science, livestock management, ecological and health impacts and economics. This strengthened nitrogen cycle perspective has been clearly recognized by the Organisation for Economic Cooperation and Development (OECD) who included "Nitrogen" as one of the major themes of the September 2016 Ministerial level conference of their Environmental Policy Committee (EPOC).

Consolidation of shared goals: The ENA started with 21 reasons to care about reactive nitrogen in the environment (See ENA Chapter 5), and first identified nine priority concerns, then eventually reducing this down to the five key threats. This process has clearly resulted in a much stronger public awareness. This can be illustrated by engagement with UN Environment in their publicity for the 3rd Intergovernmental Review (IGR-3) of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA, Manila 2012), where UN Environment placed the ENA diagram of the 5 Key Threats (Figure 1) centre stage, strongly preferring it to a more scientific visualization of the nitrogen cascade.

Identification of specific challenges: One of the natural outcomes of any assessment process is that it throws into much sharper relief the things that have not yet been done. In the ENA it was only toward the end of the process that Seven Key Actions were identified on what could be done to manage nitrogen better. It was clear that much more attention was needed to address these possible solutions. This challenge was taken up in the Global Overview on Nutrient Management, "*Our Nutrient World*" (Sutton et al., 2013) prepared under the lead of INI for UN Environment, as an invitation which directly followed on from its appreciation of the ENA. The same was true of the invitation to help prepare the UN Environment fast-track report "*Drawing down* N_2O" (Alcamo et al. 2013). Finally, we have already mentioned the ENA Special Report "*Nitrogen on the Table*" (Westhoek et al., 2015) which represented the continuation of work that it was only possible to start in the first phase of the ENA.

Figure 1: The Five Key Threats of too much or too little nitrogen.
This concept was introduced by the European Nitrogen Assessment and has seen a high take up by users including by the United Nations Environment Programme.



Towards the Global Challenge: The ENA represented the first continental scale multi-sector, multi-threat assessment for nitrogen and in this way has pioneered a course toward further regional and global scientific assessments. In this way the ENA clearly informed the US assessment of nitrogen and climate (Suddick et al., 2012), the California Nitrogen Assessment (Tomich et al., 2016) and the recently completed Indian Nitrogen Assessment (Abrol et al., 2017). The same can be said in Europe, where the ENA has provided a profound scientific background stimulating ongoing policy development, such as in Germany towards a German Nitrogen Strategy (SRU, 2015; Umweltbundesamt, 2015), as well as the Danish DNmark and NitroPortugal processes. Together it was the positive response to the ENA and *Our Nutrient* World that has allowed INI to develop a new process for global science-policy interaction, the International Nitrogen Management System (INMS). This process delivered in partnership between UN Environment and INI is underpinned by a major project part funded through the Global Environment Facility (GEF), called "*Towards INMS*" which was launched at the 7th International Nitrogen Conference in Melbourne, Australia (December 2016). Among the planned outcomes, is the expectation to develop the concept for and produce the first global International Nitrogen Assessment.

Future research challenges

So what are the research challenges for the years ahead and how do these relate to TFRN, INI and INMS as examples of delivery pathways to policy makers and the public? We use the same themes as above to reflect on these challenges.

Nitrogen cycle perspective: The first major need is to continue to focus on solutions for better management of the nitrogen cycle. Here the challenge must be increasingly to join up scientific knowledge on multiple sources and multiple impacts of nitrogen flows to provide more coherent guidance to governments and actors involved in key nitrogen flows. Key outcomes from TFRN have included the production the Ammonia Guidance Document and Ammonia Framework Code (Bittman et al., 2014; UNECE, 2015) for the UNECE Geneva Air Convention, which now also provide reference documents for the recently revised EU National Emissions Ceilings Directive (the National Emissions Reductions Commitment Directive, Directive 2016/2284/EU). These documents present a compendium of practical measures for mitigating ammonia that have been endorsed by the European Farmers' organizations prior to their adoption by the UNECE. At the same time, these primarily air quality oriented measures were identified in consideration of the entire N cycle, for example focusing not only on emission reductions measures, but also farm nutrient balances.

The adoption of these documents by the EU shows the importance of this contribution, including the need to keep these documents up to date in future. The emerging challenge however, is to now develop more coherent guidance for nitrogen management, that links minimization of losses of ammonia, nitric oxide, nitrous oxide, nitrates and di-nitrogen etc, with a focus on improving nitrogen use efficiency at different scales, from farms, to the food chain and the wider economy. Already the European Commission (DG Environment) has demonstrated its interest in this goal, with TFRN hosting a first workshop (October 2016): "*Towards joined-up nitrogen guidance for air, water and climate co-benefits.*" The process of preparing this guidance will necessarily impose new requirements on underpinning research to understand and quantify the synergies and trade-offs between nitrogen forms, to show how reduced pollution can translate to improved nitrogen used efficiency, and to show how linking nitrogen forms can demonstrate the cost savings to be made in order to mobilize the "nitrogen circular economy".

Consolidation of shared goals: With the ENA having already demonstrated the strength of working together on the five key threats of excess nitrogen, the next phase must continue to emphasize this challenge. For example, the five threats were reviewed in a preparatory workshop for INMS supported by the UK funded INMS pump-priming project (Edinburgh, April 2015). This gave continued support to the same five threats, but added that increased emphasis should be added for the interactions with food and energy production and use, where there are both massive benefits of nitrogen use, but also substantial threats associated with stability and availability of supply. Steps have already been taken in this direction in the valuation of externalities of nitrogen pollution, with an update of the ENA numbers by van Grinsven et al. (2013) pointing to societal costs from European nitrogen pollution of 75-485 billion Euro per year, with these numbers being even bigger than the direct agricultural benefits (based on value of crops produced). Challenges in taking such numbers forward include more comprehensive valuing of the full benefits of nitrogen in food and energy chains, as well as setting the European numbers in the global context to further build the "gravity of common cause" around the need for better management of nitrogen flows.

One of the major research challenges for the next 5 years must be in developing more coherent spatial and temporal modelling of all major aspects and impacts of the nitrogen cycle, as a basis to assess scenarios of future nitrogen use, benefits and pollution. These are needed to show what may happen if the problem is ignored, and conversely what benefits may be achieved if the nitrogen challenge is addressed through improved practices and policies. Already many of the building blocks are available as component models dealing with sources such as agriculture, transport, emission, atmospheric chemistry, deposition, soil, water and river transfer, food choice and the costs of taking action. However, a much more coherent approach needs to be developed that enables shared input datasets to be better used to allow improved comparability and to allow outcomes from one model to feed into others (e.g., linking emission to transfers and impacts; coupling maximization of nitrogen economic benefits with minimizing the environmental costs). In particular, a much stronger emphasis is needed on linking regional and global scale modelling of impacts on atmosphere, terrestrial ecosystems, freshwater ecosystems and the coastal zone.

Identification of specific challenges: Within this wider context of the need for integration, there is still further need to address specific parts of the nitrogen cycle. Two clear examples can be given.

Reducing the big N losses: Firstly, the increasing emphasis on nitrogen use efficiency highlights the need to reduce surplus inputs and all the major nitrogen loss terms to maximize their useful cycling. This points to the importance of better quantification of di-nitrogen (N_2) losses through denitrification and the need to understand better how they may be reduced. In the past, denitrification has been considered as beneficial in some contexts, e.g. waste water treatment, reduction of NO_x emissions through catalytic and non-catalytic reduction. However, it increasingly becomes clear that this is wasting a valuable resource. If all the European

N losses estimated by the ENA are added up, this amounts to 22 million tonnes per year (Leip et al., 2011). Multiplying this by a nominal fertilizer price of €0.80 per kg N shows that Europe is losing around €18 billion as a cash value of nitrogen every year. With the agriculture share of this waste amounting to €14 billion, this represents around 25% of the EU Common Agricultural Budget – or 10% of the entire EU budget – going up in smoke or down the drain as a result of nitrogen losses. The estimated component losses are: denitrification to N_2 €7 billion; losses to water pollution €4 billion; and losses to air pollution emissions €6 billion, and this is just the cash value, before even starting to count the societal costs associated with human health, ecosystems/biodiversity and climate as estimated by the 2011 ENA and van Grinsven et al. (2013). The scale of these numbers points at strongly emphasizing N recycling, including developing improved technologies for NO_x recycling to produce nitric acid and nutrient recovery and recycling technologies for organic wastes (Sutton et al., 2013, Chapter 6).

Changing priorities following emissions reductions: While reducing nitrogen pollution from agriculture in Europe has proved difficult, for each of ammonia emissions, nitrate leaching and nitrous oxide, much larger progress has been made, or is committed to be made in reducing nitrogen oxide emissions from combustion sources in Europe, including electricity generation and traffic. Although the failure to meet planned NO_x emission standards in vehicles has been widely publicized (e.g., as a result of the Volkswagen emission scandal of 2016), the reality is that emissions have still decreased substantially, with the EU taking on a commitment to further halve NO_x emissions by 2030. This highlights the need to now give increased attention to NO_x emissions from soils, which are specifically excluded from the revised Gothenburg Protocol (2012) and the revised National Emissions Ceilings Directive (2016). The exclusion was based on the fact that few countries reported these numbers, leading to lack of a level playing field. However, now that combustion NO_x emissions are decreasing, soil NO_x emissions which just like NH_3 and N_2O derive from agriculture are contributing an increased share. This is illustrated in Figure 2 which compares the agricultural share of NO_x emissions for European countries for 2006 and 2014, with it being likely that these shares will double by 2030 so that further abatement will increasingly fall upon agriculture. (The initial analysis summarized in this figure by Ute Skiba draws on emission factors of Lui et al., 2017). This observation highlights the need to prioritize refinement of soil NO_x inventories, get them implemented by countries, and emphasize the win-wins between reducing agricultural NO, NH_3, N_2O, NO_3 and N_2 emissions.

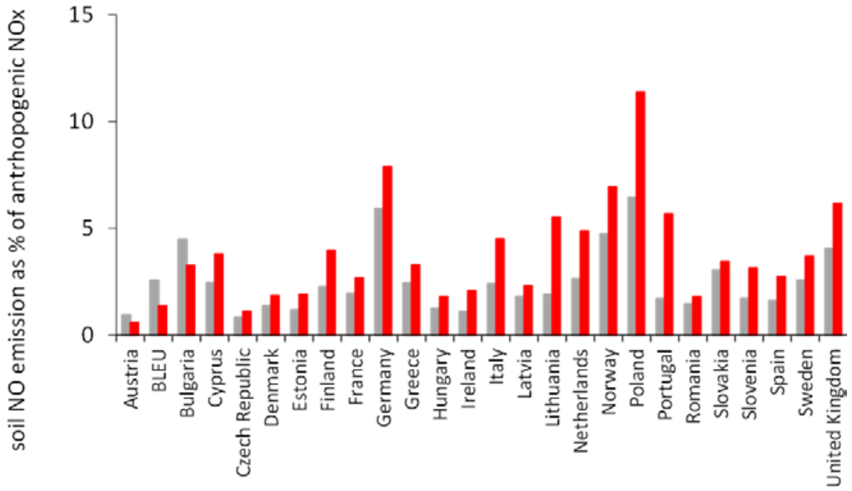


Figure 2: Estimated percentage of national nitrogen oxides (NO_x) emissions that result from agricultural soils for 2006 (grey bars) and 2014 (red bars). With decreasing NO_x emissions from combustion sources, the agricultural share in Europe can be expected to double by 2030.

At the same time it must be acknowledged that ammonia represents a major air pollution challenge for Europe, both because of its contribution to secondary particulate matter formation, with risks to human health and visibility, and because of its substantial impact on natural habitats, as highlighted by wide-scale exceedance of critical loads in Europe. There has been a growing body of evidence across Europe that per unit of nitrogen deposition, dry deposition of gaseous ammonia has a more significant effect on sensitive ecosystems than wet deposition of ammonium and nitrate in rain (Sheppard et al. 2011). Yet these differences between nitrogen forms are still not reflected in the critical loads methodology. More detailed experimental study is vital to understand these differences. From an air quality perspective, ammonia can seem like the elephant in the room, especially in to discuss how to reach farmers with a mixture of carrot and stick, but also linked to behavioural change and chances to improve efficiency, making use of a resource that would otherwise be wasted

At the same time it is noted that the UNECE NH_3 critical levels were last revised in 2007, a decade ago (Cape et al. 2009; Sutton et al., 2009), while the critical level for NO_x has stood unchanged (at 30 µg m^{-3}) since 1992 (Ashmore and Wilson, 1992). Collecting the experimental and observational evidence to update these thresholds must be a priority.

Towards the global challenge: With INMS now starting, there is a major opportunity for Europe to continue to show scientific leadership in the emerging challenges. Several key themes should be highlighted. Each of these points highlights the need to increasingly link biophysical and biogeochemical sciences with social and economic perspectives. The foundation must be toward further development and consensus building on shared indicators that have resonance across the traditional disciplines. For example, the EU Nitrogen Expert Panel has focused on developing a relatively simple Nitrogen Use Efficiency (NUE) indicator for cropping situations (Oenema et al., 2015) and the ongoing challenge must be to build consensus around approaches for full chain nitrogen use efficiency (including for the food chain, e.g., Sutton et al., 2013; Westhoek et al., 2015) and economy wide NUE, providing maximum flexibility and opportunities to reduce pollution and increase economic outputs simultaneously (Bleeker et al., 2013).

Food choice continues to be a major theme for nitrogen, especially since food choices dominate personal nitrogen footprints, and food has the potential to raise public awareness of the nitrogen challenge. Here is it significant that the TFRN Expert Panel on Nitrogen and Food is now working on a new assessment that will more closely link food choices to environment, health and wellbeing. The engagement between TFRN and the WHO (World Health Organisation) Regional Office for Europe is a new step, which brings with it the prospect to show how environmental narratives (weaker issue concerning political and public support, but very robust conclusion) and health narratives (stronger public and political issue, but potentially more contentious conclusions) can re-inforce each other.

All of these issues feed into the development of INMS. This includes the development of joined up guidance on practices with multiple co-benefits for water, air, climate, ecosystems, soils, food and energy, and applies equally to the development of models and future scenarios, with all these elements feeding into the first International Nitrogen Assessment. As part of INMS, the preparation of regional demonstrations of improved nitrogen management provides the basis for case studies that can feed into the global assessment. Here a strong emphasis needs to be placed upon understanding how priorities vary between regions and seeing how integration across multiple issues of the nitrogen cycle can help overcome the barriers to change. The INMS East Europe demonstration is focused especially on the Dniester, Prut and Lower Danube as these feed into the Black Sea. However, this East European demonstration also needs to be set within the wider context of challenges faced by countries in Eastern Europe, Caucasus and Central Asia (EECCA). In this way it can provide a focus for future action under the TFRN Expert Panel on Nitrogen in EECCA countries.

Together these case studies will provide material to better understand Europe in relation to other world regions. This is especially as issues such as the global nature of agricultural markets can act as a barrier to adoption of better nitrogen management practices in Europe, unless these can be demonstrated to be economically more profitable for farmers.

Policy Arena for Nitrogen

It would be inappropriate to finish this overview without briefly mentioning the developing policy arena for nitrogen. By this we refer to the fact that nitrogen issues feature in many different policy spaces and that there is a challenge for scientists to stimulate more informed discussion with policy makers on how this could become more effective in future. The role of science here is to point out the linkages and synergies (from a natural science perspective), but it is also relevant from a social science perspective to understand better what works best in different policy fields and what are the critical factors to success. The policy arena for nitrogen is illustrated by Figure 3, which shows how policy for water (e.g. the GPA), air (e.g. the LRTAP Convention, or “Geneva Air Convention”), climate (the UNFCCC), for biodiversity (CBD) and for stratospheric ozone (Vienna Convention and Montreal Protocol) all continue their work in parallel, but with very little mutual interconnection.

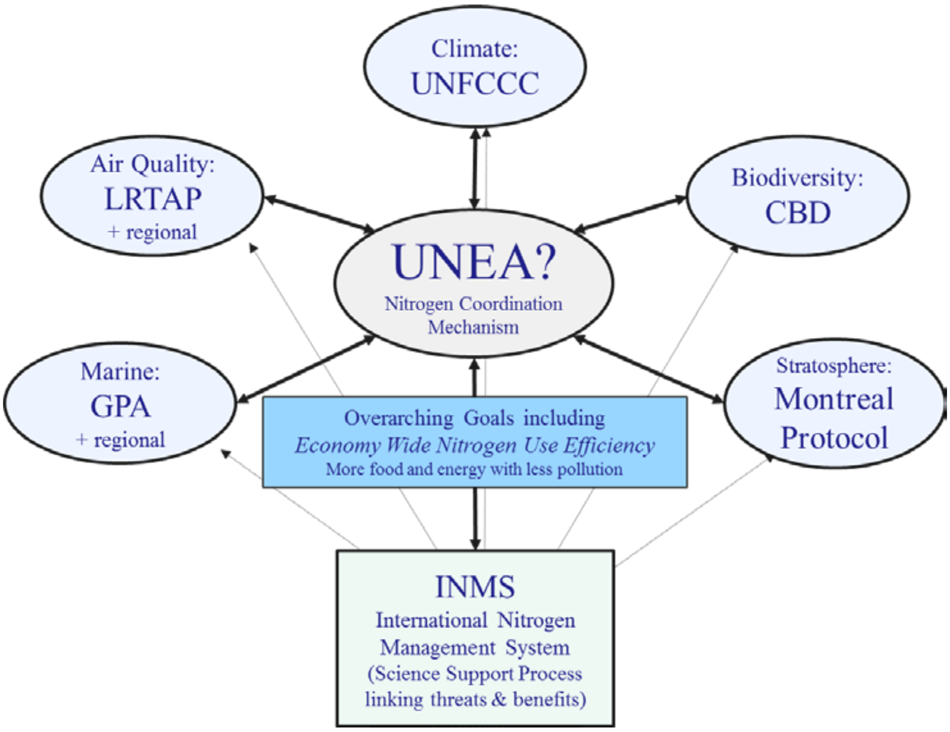


Figure 3: Simplified view of the Nitrogen Policy Arena, indicating the possible role of INMS in providing science support on nitrogen to different intergovernmental processes on water, air, climate, biodiversity and stratospheric ozone depletion, and the possible role of the United Nations Environment Assembly (UNEA) in establishing a Nitrogen Coordination Mechanism to facilitate more joined up strategy development and implementation.

Many gaps can be seen in this simplified image, which focuses on the concept rather than comprehensiveness. For example, the Parma Declaration on Environment and Health (WHO Regional Office for Europe, 2010) is highly relevant for nitrogen and food, with the follow-up Ministerial conference taking place in summer 2017. A more comprehensive version of this diagram has been drawn by Sutton et al. (2016).

Acronyms: GPA: The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities; LRTAP: The Convention on Long-range Transboundary Air Pollution (the Geneva Air Convention); UNFCCC: The UN Framework Convention on Climate Change; CBD: The UN Convention on Biological Diversity.

While INMS can and should feed directly in to each of these policy processes, there is also the question of how the policy processes, benefitting from INMS, can start to engage directly between each other. At present, it is clear from speaking with many policymakers that there is no appetite for a separate "Nitrogen Convention". However, it remains an open question what form the Nitrogen Policy Arena should take in future. For example, can the UN Environment Assembly (UNEA) offer a connecting point to develop a future "Nitrogen Coordination Mechanism"? This could work to improve mutual understanding across the Nitrogen Policy Arena, while providing a primary policy home for science support from INMS. In parallel, further effort is needed to embed nitrogen issues across sustainable development policies and in relation to the UN Sustainable Development Goals, which could provide a mechanism to support the transfer of solutions know-how. In this way, the hypothesis is that an increased focus on the multiple benefits of managing the full nitrogen cycle could help drive broader environmental agendas, such as for oceans, air quality and biodiversity.

The question of developing the Nitrogen Policy Arena, has recently been discussed at the main negotiating body of the Geneva Air Convention (the Working Group on Strategies and Review) in as part of a special workshop on Agriculture and Air Quality (1-2 June 2017). The next steps include feeding into the 4th IGR of the GPA (23-27 October 2017, Bali) and then the 3rd UNEA (4-6 December 2017, Nairobi). The discussions arising from the DNmark Conference and from TFRN will be important in feeding into this process, which can be expected to develop hand-in-hand with INMS over the next five years. As part of this, the ongoing process of multi-actor engagement between policy makers, scientists, farmers, industry, civil society and others must continue to be developed through networking across a broad range of partnerships.

Acknowledgements

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Nitrogen losses following food-based digestate and compost applications to agricultural land

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Background and aims

The anaerobic digestion of food waste for energy recovery produces a nutrient-rich digestate which is a valuable source of crop available nitrogen (N). As with any ‘new’ material being recycled to agricultural land it is important to develop best management practices that maximise crop available N supply, whilst minimising emissions to the environment. The objective of this study was to measure N losses following application of food-based digestate, green/food compost and green compost to agricultural land via ammonia (NH_3) volatilisation and nitrous oxide (N_2O) emissions to air, and nitrate (NO_3) leaching to water, and to compare these with losses from livestock manure (slurry and solids farmyard manure –FYM).

Method

Food-based digestate, compost and livestock manure were applied to agricultural land at 3 sites in England and Wales representative of the major soil types and agroclimatic zones. The solid materials were broadcast applied, with the liquids (digestate and slurry) also applied using a bandspreader. Following spreading, NH_3 emissions were measured for 7 days using wind tunnels, N_2O emissions were measured using static chambers for 12 months and NO_3 leaching was measured at one site only (on a light sandy soil) using Teflon cup samplers.

Results

Ammonia emissions were greater from applications of food-based digestate (*c*.40% of total N applied) than from livestock slurry (*c*.30% of total N applied) due to its higher ammonium-N content (mean 5.6 kg/t compared with 1-2 kg/t for slurry) and elevated pH (mean 8.3 compared with 7.7 for slurry). Whilst bandspreading was effective at reducing NH_3 emissions from slurry compared with surface broadcasting, it was not found to be an effective mitigation option for food-based digestate. The majority of the NH_3 losses occurred within 6 hours of spreading highlighting the importance of rapid soil incorporation as a method for reducing emissions. N_2O losses from food-based digestates were low, with emission factors all less than the IPCC default value of 1% (mean 0.45 ± 0.15%). Overwinter NO_3 leaching losses from food-based digestate were similar to those from pig slurry, but much greater than from pig FYM or compost. Both gaseous N losses and NO_3 leaching from green and green/food composts were low, indicating that in these terms compost can be considered as an ‘environmentally benign’ material.

Conclusions

These findings have been used to develop best practice guidelines which provide a framework for the responsible use of digestates and composts in UK agriculture.

Nitrogen turnover, crop use efficiency and soil fertility in a long-term field experiment amended with different qualities of urban and agricultural waste

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Background and aims

Organic wastes contain significant amounts of organic matter and nutrients and their recycling into agriculture can potentially contribute to closing the natural ecological cycle. The aim of this study was to evaluate the improvement in overall soil fertility and soil nitrogen (N) supply capacity in a long-term field experiment with repeated application of different urban and agricultural organic waste amendments.

Methods

Soils from the CRUCIAL field experiment in Denmark, in which diverse types of urban (human urine, sewage sludge, composted household waste) and agricultural wastes (cattle slurry, farmyard manure and deep litter) have been applied annually for 11 years (at normal and accelerated rates), were used to estimate the effects of the different qualities of organic wastes on soil fertility, N turnover and crop N availability.

Results

Soil physical fertility parameters, such as water retention and total carbon, improved with the application of organic wastes. Cattle manure, sewage sludge and composted household waste in single or accelerated rates of application increased soil total N by 13-131% compared to the mineral fertiliser NPK treatment. The highest net N mineralisation capacity was observed for the accelerated rate of composted household waste, followed by all the other organic waste amendments and with the lowest net N mineralisation in the NPK-only and the unfertilised treatments. In soils amended for 11 years with NPK, human urine, cattle slurry, sewage sludge, cattle farmyard manure, cattle deep litter and composted household waste, the apparent crop N-use efficiencies (NUE, compared to unfertilised control) were 88, 73, 55, 51, 21, 16 and 11%, respectively. The continuous application of organic wastes generally increased NUE in the last year in comparison with the first year, except for composted household waste where N-use efficiency declined from 27 to 11%. The corresponding long-term mineral fertiliser N-equivalent (MFE) value ranged between 82 % (human urine) and 13% (compost).

Conclusions

The repeated application of different organic wastes to soil had significant potential for improving soil physical fertility by increasing the organic matter content in soil, which in turn improved its water-holding capacity. In the short term, N availability was clearly related to the application of organic wastes with a high proportion of inorganic N, whereas net N availability in the longer term was related to the build-up of soil N and C pools associated with the continuous application of organic wastes. Finally, we observed crop N uptake and apparent NUE to be closely related to immediate soil N availability in the first year. After 11 years of waste application, though immediate soil N availability still had a strong effect, N uptake and NUE had increased for most low C:N wastes, indicating the influence of soil TN build-up and mineralisation capacity. However, continuous application of the most C-rich and high C:N organic waste products, such as cattle deep litter and household waste compost, had a negative effect on NUE over time.

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Monitoring maize N status with airborne and ground level sensors

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Background and aims

Remote sensing might improve fertilization by monitoring crop nitrogen (N) status using non-invasive methods. The main goal of this experiment was to test the ability of proximal and airborne sensors to identify the nutritional N status of maize.

Methods

We compared various indexes and combination of indexes to select those that provided the best estimation. As airborne images were acquired from different sensors and platforms (drone and aircraft) we compared the effect of spatial resolution on the indexes calculated. The study was conducted in a field maize experiment in Aranjuez (Madrid, Spain) during 2015. The experiment consisted in a complete randomized design with five fertilizer rates ranging from 0 to 220 kg N ha^{-1} and six replications. Readings at ground level were taken with proximal sensors (SPAD® and Dualex®), and airborne data were acquired by flying a hyperspectral sensor 330 m and a multispectral camera 80 m over the experimental site. The aerial imagery was used to calculate N status indexes for each plot.

Results

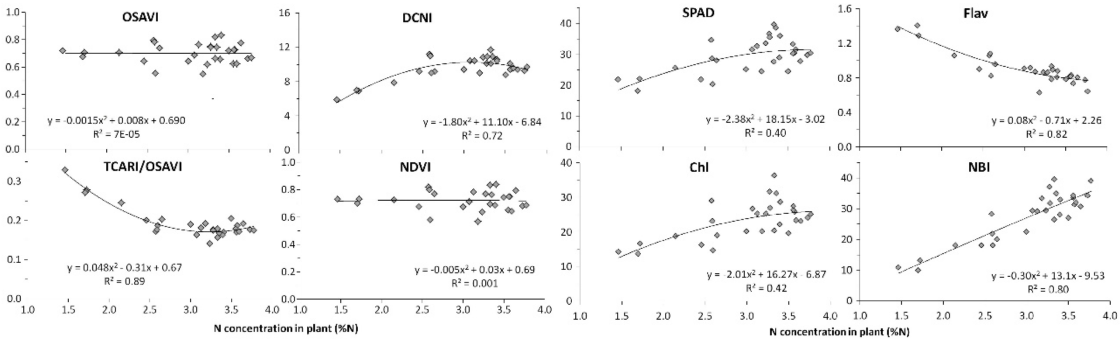

Fig1. Polynomial correlations between airborne/leaf clip indexes and N concentration (%N) observed.

Conclusions

Proximal and airborne sensors provided useful information for the assessment of maize N nutritional status. Higher accuracy was obtained with indexes combining chlorophyll estimation with canopy structure or with polyphenol indexes. Combined indexes improved the estimation compared to an individual index and mitigated the index saturation at high N concentration values. Plant N concentration was strongly related with TCARI/OSAVI obtained from airborne imagery but not with NDVI. The spatial resolution did not affect the performance of structural indexes whereas highly influenced the pigment indexes.

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Canopy double sensor for precision nitrogen fertilization

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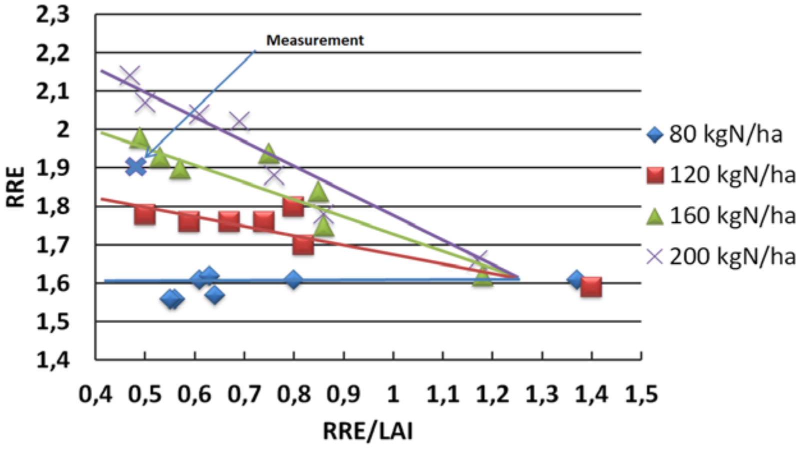
Background and aims

The MobilLas canopy sensor has been developed over many years and primarily applied to winter wheat and potatoe fertilization experiments. The instrument includes sensors for measuring both canopy spectral reflectance and structure. The current configuration includes the active spectrometer, ACR-430, measuring multispectral reflectance and a laser range finder, AccuRange 4000, with a scanning attachment measuring canopy structure including leaf area index. By combining measurements of leaf area index (LAI) and a spectral index - e.g. RRE calculated as the ratio of near infrared and red edge reflectance values– the canopy N-status can be obtained more accurately than with current single sensor instruments.

Methods

From MobilLas measurements in research plots receiving varying amounts of N fertilizer an algorithm for sensor based N fertilization can be developed. The developed algorithm can then be applied to fertilization at the field level. The algorithm shown below is developed from measurements made in a winter wheat (var. Hereford) experiment between April 15 and May 6, 2014.



The RRE/LAI ratio is proportional to leaf chlorophyll density important for the accurate determination of crop N status.

Results

The algorithm will convert a sensor measurement to an estimate of crop N-status without the need for additional information e.g. development stage. The N-status of the indicated measurement approximately 145 kgN/ha. For a target development corresponding to the application of 180 kgN/ha the sensor will recommend the addition of 35 kgN/ha at the last dressing. The recommendation based on simple interpolation. The N recommendation stable over time and sensor measurements can be made a week or more prior to the last N dressing.

Conclusion

Results from applying the N-algorithm to independent winter wheat measurements made other years and applications to entire fields will be shown. Also results from application to potatoes will be included. The limitations of sensors-based fertilization will be addressed.

Sustainable intensification and extensification of cropping system for biorefinery in Denmark-what does the nitrogen balance say?

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Background and aims

Establishing an environment-friendly industrial biorefinery production requires resource efficient agro-ecosystems with low losses to the environment, especially of nitrogen (N). This work reports the first field-based N losses and balances for agro-ecosystems optimised for biomass production for biorefinery under north-European climate and soil settings.

Methods

Data for three years at two soil types in Denmark and two novel systems, *i)* optimised rotation with annual crops, and *ii)* perennial grasses intensively fertilised (festulolium/cocksfoot), low-fertilised (miscanthus) and unfertilised (grass-legume mixture), were compared with data for *iii)* traditional systems. The comparison was based on field measured aboveground biomass N and soil nitrate concentrations, and model-supported N leaching and balances.

Results

The results (mean of 2013-2015) showed overall negative N balances, especially on sandy loam soil (Fig. 1). This suggests that a large proportion of the N taken up by the crop came from soil organic matter mineralisation. Model-estimated rhizodeposition shows large carbon (C) inputs, especially for the grasses (data not shown). Thus, the perennial grasses probably shift the soil C:N ratio, influencing soil C storage through changing soil microbial community and biochemistry.

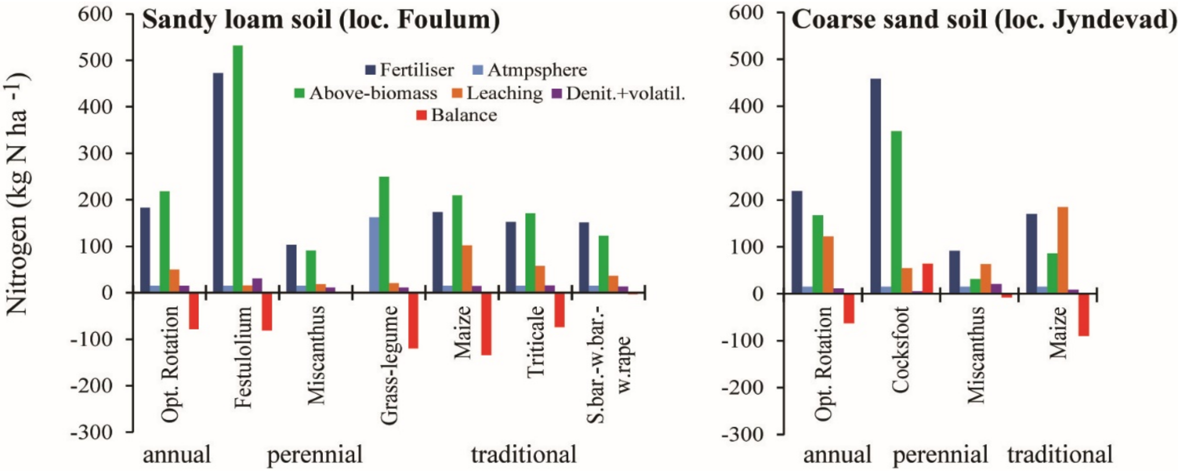

Fig. 1. Nitrogen balances for the systems. Optimised rotation is at Foulum winter rye (2012/13)-maize (2013)-winter rye (2013/14)-beet (2014)-hemp (2015)-triticale (2015/16), and at Jyndevad hemp (2012)-winter rye (2012/13)-maize (2013)-winter rye (2013/14)-winter rape (2014/15).

Conclusions

Overall, perennial grasses are the more sustainable choice due to very low nitrate leaching. However, rotations with e.g. double cropping of annual crops seem to hold almost the same potential given careful optimisation in relation to choice of crop, number and timing of harvests and fertilisations. Actual soil C change, energy and pesticide use, as well as socio-economic aspects will complement the study in future.

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Development and implementation of a simulation game for the introduction of a revised Fertilizer Ordinance in Germany

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Introduction

Germany has failed to comply with the EU-Nitrates Directive and, therefore is currently revising its National Action program. The core legislation is the so-called Fertilizer Ordinance (Düngeverordnung) that is most likely going to be passed by the federal council in spring 2017. Recent government drafts have suggested a considerable tightening of the regulations. This will lead to changes in farming practices and structures, especially in regions with high stocking densities like parts of Lower Saxony. The legislation will impact not only farmers but also the stakeholders of the upstream and downstream sectors. A successful implementation of the new legislation requires understanding and acceptance. Therefore, tools are needed to inform the farmers about the new legislation, in order to motivate and increase acceptance by the different stakeholders.

Method

A simulation game has been developed to moderate the introduction of the revised Fertilizer Ordinance. Simulation games are a suitable tool to communicate the implementation of new legislation. The participants work in a fictitious but realistically-made environment, can test adaptation strategies without risk and assume a different role to that of their actual one. In this way, they gain insights into the motives, strategies and actions required by other groups of people involved in a process. With regard to the Fertilizer Ordinance, simulated participants are organic fertilizer exporting and importing farms, policy-makers, control authorities, agricultural contractors, water associations, environmental activists, food and agricultural equipment traders and the general public. Participants take on various roles, interact and adapt to the Fertilizer Ordinance with regard to their position in the simulation. The game allows, for instance, to simulate the exchange of manure between pig fattening and arable farms or the role of the public perception. In a final discussion, participants receive an overview of the interrelations of the overall event.

In 2016, 45 agricultural students, half of whom have an agricultural background, took part in the simulation game as a pretest. In a second step, the participants were interviewed in an guideline-based interviews about their experiences.

Results and conclusion

It was found that

- the participants had not been familiar with the expected changes in the Fertilizer Ordinance,
- there was no understanding and even anger in regard to the agricultural policy,
- the willingness to conclude long-term cooperation agreements for the import of organic fertilizer is very limited on arable farms,
- a change of roles enabled an understanding of the different positions and views of the relevant stakeholders,
- the simulation game increased knowledge about the legal changes and raised awareness of the need to revise current environmental law.

The initial results from the pretest led to the conclusion that the simulation game is a useful tool to moderate the implementation of the revised Fertilizer Ordinance. Furthermore, the need to communicate on the upcoming changes was evident. In November 2017 in a further step, the simulation game will be conducted with locally involved participants, focusing on concerned farmers in Lower Saxony.

Evaluating scenarios of land management practices in contrasted landscapes using a nitrogen landscape model: Comparing the effectiveness of optimizing agricultural practices versus landscaping on mitigation nitrogen fluxes

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Background and aims

Designing mitigation strategies at the landscape scale to improve overall N efficiency and reduce undesirable emissions is a major challenge (Cellier et al., 2011). Indeed, most often, mitigation measures are conceived at field or farm scale to reduce one main type of N emission (e.g. leaching, driven by Nitrate Directive and Water Framework Directive). As part of the ESCAPADE project (ANR-12-AGRO-0003), agri-environmental scenarios of N management are built in contrasted rural landscapes to better understand the way reactive nitrogen transforms and transfers into, out of and within the agro-ecosystem (Galloway et al. 2003), depending on farm management and landscaping. The main objectives are (1) to simulate spatio-temporal scenarios under different environmental and agricultural conditions using the TNT2 model and (2) to evaluate the relative efficiency and possible complementarity of field-oriented and landscape-oriented measures to reduce N emissions in contrasted landscapes.

Methods

The two study sites are headwater catchments located in Brittany (Western France) and in Gascogne (South-West of France). They are contrasted in terms of agriculture type (mix farming with high livestock density and cereal cropping, respectively), soil, climate (warmer and dryer in Gascogne) and landscape structures. Surveys were held to describe agricultural practices exhaustively (crop rotations and crop management practices over 15 years). The scenarios are built to investigate the different ways of mitigating the nitrogen cascade 1) optimizing agricultural practices (fertilization, cover crops, manure management ...), 2) management of landscape structure according to two strategies: (i) the division of the land (ie distributing ecological structures such as vegetated/forested buffer strips around major sources or in riparian position in the landscape) and (ii) parsimonious land (implanting few patches of natural vegetation). The scenarios are simulated using TNT2, a spatially distributed agro-hydrological model focusing on the spatial interactions within the landscape (Beaujouan et al, 2002 ;. Oehler et al., 2009; Ferrant et al, 2013).

Results

The simulations are currently running. The catchment modeling will help to determine the most efficient strategy to reconcile agriculture production and mitigation of nitrogen pollution.

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A participatory protection within the Vittel mineral watershed: Making farmer the best experimenter to improve nitrogen use efficiency and water quality

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AGREV 3 (Agriculture Environment Vittel), as research-action project (Hatchuel et al., 2000), focused on a natural mineral watershed protection under 6200 ha of agricultural land. To maintain water under 10 mg of nitrates L-1 and without pesticides residues Agrivair (a Nestlé Waters entity) and INRA (French National Agronomical Institute), imagined, implemented and evaluated a re-designing of the agricultural practices and landscape with farmers. Our sharing goals are to allow a valuable farming in the watershed and to keep ability to produce natural mineral water on the long term. The landscape designed by farmers reveals at various scales logical processes and driving forces related to the soil, climate, logistic management, and economical pressures whose understanding is a major challenge for landscape agronomists (Benoît et al., 2012). To achieve it, we collect fertilization practices and soil occupation on all this watershed. Moreover, thanks to our territorial diagnosis, we design within 24 farmer's fields experimentations with 170 ceramics cups and a net of 20 surface springs. These tests taking place in situ within farms (Ceramics cups, Environmental impact of composted manure management, Cover crop experimentation, Grassland growth observatory, Nitrogen Use Efficiency tests, etc.) offer interaction between farmers and scientists.

Indicators and field measurements permit to mine large land use databases for revealing temporal and spatial organization of land use by farmers, based on crop sequences and on fertilization practices (Lazrack et al. 2013). All indicators are continuously improved by data acquisition and mining processes (farmer meeting, satellite images, grassland growth observatory, manure analyses, etc.) to increase the sensibility of the prescription for both farmers (no corn and pesticides, stacking rate, cover crop, nitrogen use efficiency, etc.) and watershed managers (territorial sensibility map, improving manure management, etc.). For example, the evolution of nitrogen leaching has been measured since 1988 with ceramic cups collecting system. All of these trials give us for farmers more than 4000 measurements points on 10 different crops.

By collecting data from farmer's fields we enhance emersion of trials carried on by farmers. It also creates opportunities to share with them indicators from measurements and thus give us the lowdown on their annual practices. Theses explanations and argumentations allow to identify, understand and build nitrogen use efficiency innovation in order to improve global knowledge for farmers, scientists and watershed managers.

Our oral presentation aims to share the methodology applied to encourage the best agronomic management practices at the watershed scale leading to a win-win situation for both farmers and watershed managers. By our work we intent to build a participatory research that leads to (i) understand the entire system and farmers perspective, through a common research question, (ii) develop appropriate agricultural practices through a common research protocol, (iii) actively involve the farmers in the entire participatory research process, focusing on data acquisition and mining processes (Conducting the research in farmer's fields), facilitating and providing new idea and/or unknown technology to the farmers, promoting innovative methodologies and flexibility, (iv) think about the type of results discussion, (v) build a continuous re-design of questions on the future of this water landscape.

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Open landscape nitrate retention mapping - rOpen

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Recent changes in the Danish legislation allows for more targeted regulation of fertilizer use in the Danish agricultural sector. This means that the amount of fertilizers can be increased in areas that are less vulnerable to leaching of nitrate to recipients. The question is how do we identify the vulnerability of the areas? It is not a trivial task defining the vulnerability as it will depend on factors such as the local climate, the hydrology, the subsurface geology, the geochemistry, the land use, and the presence of drains. Answering this question in full is therefore a complicated task requiring a coordination of: data collection, data interpretation and numerical modeling. Approximately 62% of the land area in Denmark is used for agriculture and any methodology should be applicable to with very large areas potentially open to target regulation, and thus needing a vulnerability assessment.

The recently funded research project entitled “Open landscape nitrate retention mapping” – *rOpen*, aims to provide solutions to address this question. A key aspect is the development of methods that potentially will be applicable on a national scale. This means that the developed tools and methods must be reliable, fast, and relatively cheap to implement. However, traditionally the tasks of geological modeling and development of numerical models to simulate groundwater flow have been a manual task. Such manual tasks are time consuming and thus expensive, and will therefore not be applicable on a national scale.

In rOpen, we seek to make these working procedures more effective. Many of the tasks performed in the manual work procedures are relatively trivial, and can thus be performed by computers. Of cause this requires reliable algorithms and methods. Building on the experiences of the recently completed research project HyGEM, we will utilize methodologies to develop structural models of the subsurface directly and semi-automatic from geophysical data and lithological data. Such models can be incorporated into groundwater models. An additional time consuming task is the development numerical models that can be used to simulate groundwater flow and transport of nutrients in the subsurface. To minimize the manual task associated with numerical model development, we will build an integrated modeling environment in Python that integrates the well-known model codes DAISY, MODFLOW and MODPATH.

Another key aspect of automating work procedures is the collection of large amounts of data, especially in relation to delineating the shallow structures of the subsurface. To complete this task rOpen will develop new geophysical instruments designed for such shallow mapping.

In the presentation we would like to present the entire modeling, data collection and analysis concept to be developed during the rOpen project. Despite the recent startup of the project, we can provide examples on most of the developments, and show some examples on modeling tasks and mapping results.

Designing decision support tools for targeted N-regulation – Experiences from developing and using the Danish dNmark landscape model

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Background and aims

Regulation of nitrate emission from agriculture to aquatic environments in Denmark currently depend on general rules for nutrient application and associated farm-level reporting schemes. Similar or comparable instruments based on centralized regulation of N-management exist in large parts of the OECD. Recently the Danish authorities proposed to shift the scale of regulation to a more local level to better fit relevant socio-political and agro-environmental processes, including the scale of farmers' decision making, the scale of relevant hydrological systems and the scale of key agro-ecological conditions such as soil characteristics and drainage. However, the challenge of shifting the focus of the regulation to a more local scale raises a number of questions. These include (1) How information produced locally can be integrated with national scale data? (2) In what way integrated datasets can be stored and used to model environmental effects of current and possible land use patterns? (3) In what way data and estimates of consequences of land use changes are best made available in decision making processes? To address these questions this study reports on ongoing work in Denmark to develop and improve a functioning decision support tool for landscape scale N-management. The aim of the study is to evaluate how a decision support tool can best be designed in order to enable landscape scale strategic N-management practices.

Methods

A prototype GIS-tool for capturing, storing, editing, displaying and modelling landscape scale farming practices and associated emission consequences was developed. The tool was designed to integrate locally held knowledge with national scale datasets in live scenario situations through the implementation of a flexible, uniform and editable data model for land use data – the dNmark landscape model. Based on input data which is corrected and edited by workshop participants, the tool estimates the effect of potential land use scenarios on nutrient emissions. The tool was tested in 5 scenario workshops in case areas in Denmark in 2016, on the basis of which its design is evaluated and discussed.

Results and conclusions

Based on our experiences we found that four elements are of particular importance when designing decision support tools for landscape scale N-management. These represent tasks that the tool should aid in resolving and include: (1) The formulation of an inclusive, socially acceptable common understanding of current land use patterns, conditions for production and effects on the environment among the stakeholders present; (2) Successful and appropriate handling of errors and imprecisions in the data being presented through provision of an on-the-fly editing environment, (3) The provision of an easily used and agile scenario-formulation option able to compare scenarios with the baseline situation; (4) Clear communication of the status and authority of the expertise that the tool introduces into the local setting relative to local knowledge. These and associated findings are discussed and it is outlined how the findings can contribute to the design of decision support tools. Based on recent research in the fields of collaborative planning and landscape ecology, the conceptual basis of an improved tool-design is discussed.

Acknowledgements

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Towards protecting the Great Barrier Reef from land-based pollution – a focus on nitrogen

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The Great Barrier Reef (GBR) is an iconic coral reef system extending over 2,000 km along the north-east coast of Australia. Global recognition of its Outstanding Universal Value resulted in the listing of the 348,000 km^2 GBR World Heritage Area (WHA) by UNESCO in 1981. Despite various levels of national and international protection, the condition of GBR ecosystems has deteriorated over the past decades. A major cause of this decline has been discharge of pollutants from agricultural lands; that is sediments from erosion of grazing lands, pesticides (mainly herbicides) applied to cropped and grazing lands and dissolved nitrogen originating from fertilisers applied to cropped land.

Moreover, discharges of these land-based pollutants remains a major threat to the future condition of the GBR WHA. To address land-based pollution, the Australian and Queensland Governments have implemented a range of policy initiatives since 2003. Here, we outline (i) the evidence on the decline in GBR water quality and ecosystem condition, and (ii) the policy responses by Governments. We then present (iii) the effectiveness of the existing initiatives to reduce discharge of land-based pollutants, particularly dissolved nitrogen, into GBR waters. For nitrogen, these initiatives include developing and/or promoting agronomic approaches to increasing nitrogen use efficiency, regulation of nitrogen management and development of market-based instruments to facilitate change in nitrogen management by farmers. These instruments include reverse auctions, where the government purchases from farmers reduced nitrogen discharges, and exploration of insurance as a way of helping farmers manage the risks coming from reducing nitrogen inputs to crops.

We conclude that efforts to reduce land-based pollution are not sufficient to protect GBR ecosystems from declining water quality within the aspired timeframes. To increase the likelihood of protecting GBR ecosystems into the future, we describe incremental improvements that can be made to current approaches to reducing pollutant discharges, and highlight potential transformational changes to current agricultural land uses.

Cost Efficient Regulation of the Danish Agricultural Discharges of Nitrogen to Coastal Waters – Economic analysis of total cost and the distribution of cost

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Nitrogen discharge from the Danish agricultural sector negatively affects the ecological status of Danish coastal waters. According to the Water Framework Directive, Denmark is obliged to reach good ecological status in all its coastal waters. To achieve this goal of good ecological status it is necessary to regulate the agricultural discharges of nitrogen. We analyse the cost effectiveness of several types of such nitrogen regulation, taking the national nitrogen discharge reduction targets of 2021 as given. The reduction targets are separately specified for 90 different water catchment areas.

We model the costs and impacts of different types of regulation within each water catchment area, taking account of spatial differences in farm type mix and retention rates, i.e. the soils ability to prevent leached nitrogen to be discharged to the coastal water. This is done by combining a partial equilibrium model of the Danish agricultural sector (ESMERALDA) with detailed geographic information about the joint distribution of farm types and retention rates in each of the 90 water catchments.

We find that the most cost efficient type of regulation is a targeted crop tax. Under such a tax, each farm pays a tax per hectare depending on the crop choice as well as the soil type, the local retention rate and the size of the local reduction target in the water catchment area. The tax is higher if the reduction target is high, if the retention is low or if the leaching from the chosen crops is high. The crop tax is combined with a targeted tax on livestock units, which corresponds to the extra discharge caused by using manure instead of artificial fertilizers.

We also find that regulation based on the principles of the former Danish regulation system – so-called nitrogen allowances – is more costly than the targeted crop tax. This is true even if the nitrogen allowances are targeted towards differences in retention rates and reduction targets. Nitrogen allowances are more costly because they impose regulation further away from the environmental impact, i.e. on input of nitrogen instead of on discharges.

A targeted crop tax has additional beneficial features. We show that a targeted crop tax gives better incentives than nitrogen allowances to place high-emitting production where reduction targets are low and where the retention rate is high. We also show that a targeted system of nitrogen allowances gives incentives for farmers to trade nitrogen illegally, because the value of one kg will differ severely between some farmers. We estimate the costs of achieving the reduction targets if such trade takes place. These costs can more than quadruple the cost of achieving the reduction targets in all catchment areas. Targeted crop taxes do not suffer from such adverse incentives to illegal nitrogen trading.

Finally, we consider distributional impacts of different types of regulation. We suggest a transfer mechanism, which returns the tax revenue to farmers without causing adverse incentive effects. We show that this transfer mechanism makes targeted crop taxes the least costly type of regulation for most farmers.

A sectorial and integrated approach to solve the Nitrogen Problem is necessary

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The release of reactive nitrogen into the environment is still one of the biggest environmental problems in Germany. For example, 48% of the country's natural and semi-natural terrestrial ecosystems suffer from eutrophication (2009), some 28% of Germany's groundwater bodies exhibit a poor chemical status (2012-2014), and the long-term limit value for nitrogen dioxide in ambient air is exceeded at more than 60% of urban traffic stations (2015).

The main sectors responsible for nitrogen emissions are agricultural activities and combustion processes (energy and transport). The German Advisory Council on the Environment (SRU) has analysed these sectors and has given a number of recommendations with regard to reduction measures in these areas (SRU 2015). Within the agricultural sector for example it is of great im-portance to enact more stringent requirements for manure application methods and to im-prove the enforcement of the Fertilizer Regulation. In this context the implementation of a "farm gate balancing" to calculate the nutrient surplus (the nutrient balance going through the farm gate) is important. In addition, a tax should be imposed on the nitrogen surplus of individual farms. With regard to combustion plants, the SRU recommends that a coal phase-out strat-egy is elaborated and that stricter limit values for power plants using fossil fuel and biomass are enacted. In order to reduce nitrogen dioxide emissions from the transport sector, environ-mental zones should be improved and the tax advantage for diesel cars should be abolished.

However, if the nitrogen problem is only viewed in terms of individual sectors or specific re-sources, there is a risk that impacts will simply be shifted elsewhere. As an example, the con-flicts between bioenergy policy and nitrogen pollution have not been taken into account at an early stage. The SRU recommends therefore, that a national nitrogen strategy with an inte-grated approach is developed in order to identify unintended consequences at an early stage. By bringing together existing targets and ordinances, the strategy will help to overcome the current fragmented approach. Furthermore, a national nitrogen strategy helps to ensure that the nitrogen problem in Germany receives the appropriate and necessary attention from pol-icy-makers, administrators and the public realm. The nitrogen strategy should be jointly elabo-rated by the federal government and Germany's regional-state governments. To avoid piling up strategies which have little or no influence on political decision making processes, the nitro-gen strategy should be developed in the context of other strategy processes at the European and national level, e.g. along the lines of the structures of the recently reissued National Strat-egy for Sustainable Development and the National Strategy on Biodiversity.

SRU 2015: Nitrogen: Strategies for resolving an urgent environmental problem. (Abstract of the main report; available online at: http://www.umweltrat.de/SharedDocs/Downloads/EN/02_Special_Reports/2012_2016/2015_01_Nitrogen_Strategies_summary.html ; For partial translations in English of the main report see: http://www.umweltrat.de/EN/Reports/SpecialReports/specialreports_node.html)

Comparing measures for nitrogen reduction in northern Europe

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The Water Framework and Nitrate Directive outline the basis for the regulation of the aquatic environment in Europe in terms of standardizing the objectives (good ecological status) and the planning process (emphasizing cost effectiveness, participation and river basin scale), however, analysis of the implementation of these common frameworks shows that the directives are often not implemented similarly in practice. This is an issue in terms of legitimizing the regulation with the farmers, who feel that different rules apply to farmers in different countries and to ensure that the same policy targets are met.

In this paper we will conduct a comparative analysis of how the selection of policy instruments takes place in 6 different member states (Denmark, Sweden, Netherland, Poland, Germany (emphasizing Schleswig-Holstein and Niedersachsen) and France (emphasizing Brittany). The countries and the regions comprise an interesting case study because the agricultural structure and the challenges of implementing the EU directives are comparable. The paper is based on qualitative interviews with stakeholders, government officials and selected experts as well as a desktop study of various administrative documents that outline the selection of different policy tools.

The presentation documents that various approaches for approving policy instruments apply in different countries and how different policy traditions regarding the scientific evaluation of instruments and political decision-making yield a differentiated composition of policy instruments in the different countries and no common procedure is established for selecting policy instruments.

From field to factory: shifting regulatory focus to reduce nitrogen pollution

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Nitrogen (N) pollution has recently emerged as one of the most important environmental issues of the 21st century, with agriculture its dominant source. The key to managing agricultural N pollution is the synchronization of soil N supply and demand. Yet, while technologies and practices to reduce N pollution across a range of agricultural systems and climates do exist there has not been a significant increase in their use over the past several decades, even in highly industrialized agricultural sectors such as the U.S. The current U.S. approach of using voluntary initiatives to improve nutrient management at the farm-level has had little effect.

It should not be surprising that changing the practices of millions of farmers to reduce a diffuse pollution source is a challenge. Instead, what has often proven particularly effective in a U.S. context and elsewhere is when environmental policies have targeted a relatively small number of actors and pollution sources: for example, the six corporations controlling over half of the U.S. automobile market that were mandated by the Corporate Average Fuel Economy (CAFE) standards to increase the fuel efficiency of their vehicles. Within this set of cases, policies are often most successful when the small group of actors targeted by a policy can also financially benefit from it, such as DuPont under the Montreal Protocol. Consequently, this study asks whether agricultural N management efforts in the U.S. could target a smaller number of actors than the millions of farmers that are the focus of current policy? And if so, what would such a policy approach look like? We argue that one approach would be to use the CAFE standards as a model for regulating the fertilizer industry. These standards would mandate a progressive increase in the proportion of enhanced efficiency fertilizers (EEFs) in traditional fertilizer over time, giving farmers no choice but to use more efficient fertilizer products.

In order to better understand the potential economic and environmental impacts of CAFE-type standards on the fertilizer industry, we compare two policy scenarios in the U.S. corn sector (the crop planted on the most acreage and with the highest N application rates in the U.S.): Scenario 1 represents a policy to increase the area of US corn cropland using EEFs from 12% in 2016 to 30% in 2030, while Scenario 2 represents an increase to 50% in 2030. Both scenarios spark an increase in fertilizer industry profits, avoided environmental damages, and farmer economic welfare relative to business-as-usual. However, while the more ambitious scenario 2 creates greater economic gains overall, farmers must absorb an increase in their overall N costs due to the price premiums associated with EEFs. That being said, the economic impact on farmers and industry is vastly outweighed by the potential environmental and health benefits – by 2030, they could amount to \$11-\$18 billion. While there is still much work to be done to properly evaluate the costs and benefits of a CAFE-type fertilizer standard, this study illustrates its potential as a unique opportunity to avoid many of the difficulties faced by traditional policy approaches for managing agricultural N pollution.

Effectiveness of markets in nitrogen abatement: A Danish case study

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Background and aims

Degradation of water ecosystems caused by excessive loads of nutrients from agricultural sources continues to be a problem in many countries. Targeted regulation has been suggested for implementation of nitrogen (N) abatement measures to achieve N reductions. Achieving cost-efficient implementation of N abatement actions may depend on farmers' response to the suggested policy. In this study we present a method for analysing farmers' likelihood of engaging in N abatement trading contracts.

Methods

A questionnaire including a choice experiment (CE) was distributed by email during winter and spring 2016 to around 10,000 Danish farmers, resulting in an effective data sample of 923 respondents. Farmers were asked to choose between meeting an individual abatement cap in kilo N for the farm or trade N allowances with other farmers. Based on the provided answers, farmers were divided into two groups: farmers who could be interested in supplying N abatement to a market and farmers who could be interested in purchasing N abatement from the market. Each of the groups was presented with a choice experiment from where we derive demand and supply functions for trading N abatement.

Results

We find that farmers do reveal willingness to trading N abatement. However, a large proportion of farmers choose to opt-out, and the estimated demand and supply curves are therefore very price inelastic. We find that more respondents in catchment areas with high abatement caps are potential buyers, while in catchment areas with low abatement caps respondents are more likely to be providers of N abatement. We discover large heterogeneity between farmers in terms of the choice between buying and providing N abatement, the amounts they are willing to trade, and the different attributes important for the trading contracts.

Conclusions

We conclude that introducing trade as an N abatement policy measure involves challenges due to the spatial specificity of the abatement targets leading to small markets and lack of heterogeneity among farmers within the market. The results can be used to support the design of policy incentives used to address nutrient reductions.

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Groundwater nitrate response to sustainable nitrogen management

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Background

Protection of groundwater has a high priority in Denmark in order to secure a sufficient drinking water quality and a satisfactory low groundwater impact to groundwater dependent aquatic ecosystems. Groundwater protection and remediation of groundwater pollution treats is being addressed at the source of the pollution to ensure that only simple treatment at the waterworks, as aeration and filtration, is necessary. Removal of nitrogen (N) at the waterworks is not an issue. At the same time Denmark has a long tradition for intensive agricultural plant and animal production. Agricultural nitrogen management is challenging the protection of groundwater and other environments from reactive nitrogen forms as for example nitrate.

Methods

In other to address the sustainability of nitrogen management in Danish agriculture groundwater nitrate monitoring data representing groundwater recharged during the last almost 70 years are analyzed in relation to agricultural nitrogen balances and economic growth.

Results

It is shown that regulation of nitrogen management in Danish agriculture during the last three decades has had a clear effect on improvement of the groundwater quality in regard to nitrate. Since the 1980s, regulations implemented by Danish farmers have succeeded in optimizing the nitrogen (N) management at farm level. The N-surplus (N-output/N-input) has significantly been reduced, the farming N-efficiency has increased, and the N losses to the aquatic and atmospheric environment have been significantly reduced (Dalgaard et al., 2014). Accordingly, since the 1980s the overall national upward trend of the nitrate concentrations in oxic groundwater has been reversed (Hansen et al., 2011).

Conclusions

Currently, Danish regulation on nitrogen management is undergoing changes from less national regulation to more targeted regulation challenging future groundwater protection and sustainable nitrogen management in relation to groundwater.

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Session B2: Monitoring and trends assessment

Assessing nitrogen-mass flows between sub-systems within dairy farms

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Background and aims

Reactive nitrogen is an important growth-limiting factor in biological systems as well as a main source of greenhouse gas emissions. Due to its ambivalent property, it is obvious to follow the maxim to use as much as necessary and as little as possible. This requires a target-oriented strategy which focusses on the efficiency in the use of reactive nitrogen. To assess N-efficiency during the flow through different sub-systems of a farm can provide benefits for both, reducing costly N-inputs and simultaneously N-emission into the environment. The objective of the current study was to implement a new methodological approach (Machmüller & Sundrum, 2015*) for quantifying and monitoring the N-flow through sub-systems of dairy farms, to assess the degree of N-efficiency and to identify possible farm specific solutions.

Methods

To get access to the quantity of N-input and output as well as to capture the cycling of N within the farm, the latter is structured in four separate, nonetheless directly linked sub-systems: feed storage, livestock, dung storage and utilized agricultural area. N-input and output were quantified by comprehensive data sets of on-farm parameters and by making use of various estimating equations. Thereby a quantifiable portion of N-output from each sub-system serves as the N-input of the following sub-system. This enables the assessment of the efficiency by which N is transformed within each sub-system and in the total farm system. Annual N-turnover and -mass flows were assessed on 36 dairy farms, representing the range of different farm structures, sizes and locations in Germany.

Results

Quantification of N-balances and N-mass flows revealed a high variability between farms. This applied also for the N-efficiency in the different sub-systems within and between the farm systems. N-surplus of farm balance sheets yielded 146 ± 65 kg N/ha. The amount of the farm-N-surplus was determined in the first place by the farm's harvest yields and by the fertilization management. N-export by sold plant and animal products was approximately 44 ± 18 % of the imported N into the farm. With 45.8 ± 14.5%, mineral fertilizer accounted for the highest portion of N-input, followed by bought-in feedstuffs (33.7 ± 14.4%). Sold milk covered 25.1 ± 9.1 of the total N-output of the farms. Efficiency in N-use differed considerably between the sub-systems, indicating that each farm has its own options to strive for an improved N-efficiency. The calculations based on the new methodological approach showed that the farm-N-surpluses and their inherent emission potentials were considerably underestimated by farm balance sheets.

Conclusions

The quantification of the N-flow through sub-systems of a farm offers an appropriate approach to assess the magnitude of N-emissions from dairy farms. Data sampling and documentation can be easily supported by a software program. Simultaneously, the assessments indicate the farm specific options to increase efficiency in the use of N and to decrease costly N-input via mineral fertilizers and/or bought-in feedstuffs without necessarily compromising productivity.

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Map-based screening to achieve cost-effective spatially targeted WFD river basin action programmes

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Excess nitrate-nitrogen enters streams and rivers, as a result of agricultural production and other diffuse and point sources, and is transported to our coastal waters leading to both eutrophication and low levels of dissolved oxygen. Denmark with its intensive agriculture and 7500 km long coastline with shallow estuaries and coastal waters is particularly vulnerable. Despite three decades of nitrate emission reduction, further reductions are needed to meet the requirements of the European Water Framework Directive (WFD) and are associated with significant costs. Denmark's second-generation river basin management plans (RBMPs) are estimated to have a direct cost of 200 million euros when fully implemented. The Danish Commission on Nature and Agriculture and the Danish Economic Councils recommend that the Danish WFD action programmes should be spatially targeted, cost-effective and holistic. Furthermore, in the 2nd and 3rd generation river basin management cycles (2015-2027) EU Member States are required to integrate climate change into these plans.

To address these challenges, we have developed a simple but powerful map-based scenario tool to support the evaluation of nitrate management options. Building on earlier work this tool allows users to build and evaluate different nitrate management scenarios by assigning appropriate measures in a GIS environment from a pre-defined catalogue of measures. Adding new types of measures or defining new scenarios is straightforward. For each planning scenario, the nitrate reduction at specified target sites and cost-effectiveness are evaluated as well as the impacts on greenhouse gas (GHG) emissions. In this paper, we present the application of this tool in two Danish river basins, the Odense River Basin and the Roskilde Fjord/Isefjord River Basin.

We show how this new tool can be used to achieve important cost reductions, which meet environmental targets, by spatially targeting the application of measures. We also show how basin-scale management scenarios derived from this tool can be transferred efficiently to river basin scale models for a more comprehensive assessment of the impacts. Finally, we present some recent work to show that by selecting appropriate measures, synergies can be achieved in reducing both nitrate and GHG emissions. The most important value of this tool however may well be the potential to support participatory water planning by non-model experts and stakeholders.

Adoption of precision agriculture technologies for efficient nitrogen application and greenhouse gas emissions mitigation in the EU

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Precision agriculture technologies have the potential to reduce greenhouse gas (GHG) emissions from agricultural activities and maintain or improve productivity. We focused on a precision agriculture technology package consisting of machine guidance plus variable rate technology (VRT) for nitrogen application since this package has potential to reduce NO_2 emissions associated to mineral fertilisation. In the USA, surveys conducted by USDA estimated the adoption rates of VRT for nitrogen application at 8-11% in wheat area in 2009 and 10% in corn area in 2010. This suggests that adoption of technology package is still low but additional market data shows growing interest for farmers. The main reasons for the low adoption - according to economic research - are the current cost of the technology and the perception by farmers of low productivity gains from its use.

The current and potential uptake of these technologies by EU farmers is not well known. We have conducted a survey of approximately 1000 farmers in five different EU countries to fill this gap. In our survey we targeted arable crops (wheat and potato) and three types of technology adopters: i) those with Global Navigation Satellite Systems installed (a pre-requisite for VRT adoption) and using VRT for nitrogen application (full adopters of the technology), ii) farmers with GNSS but not using VRT (partial adopters) and iii) farmers who have no GNSS available (non-adopters). The regions selected present typically surplus nitrogen use per ha. A semi-structured questionnaire was used to illustrate the socio-economic profile of farmers and the farm characteristics necessary for the use of VRT and machine guidance in the EU, as well as site-specific estimates of cost and benefits. Estimates on the GHG emission reduction potential of these technologies will be also calculated for these crops/regions systems. Our findings will provide information of the socioeconomic impact of these agricultural technologies and their potential for mitigation that can be used for the EU 2030 climate policy development.

Documenting the effect of nitrogen mitigation measures by monitoring root-zone nitrogen concentration and nitrogen transport in streams

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In Denmark, measured nitrate concentration in soil water and in streams has been used as a means of monitoring the impact of agricultural mitigation measures to reduce the nitrogen (N) load to the aquatic environment. The measurements are a part of the Danish Agricultural Monitoring Programme (NOVANA) and are carried out in five small agricultural dominated catchments covering differences in climate, soil types and farming practices within the country.

The implemented agricultural mitigation measures resulted in lower consumption of commercial fertilizer, improved utilisation of N in manure as well as more efficient and increased use of catch crops in periods with high percolation and leaching. The mitigation measures have reduced the surface field balance of the individual catchments between 24 and 102 kg N ha^{-1} during 1991-2015. The highest reduction in the surface N balance was achieved in catchments with high livestock intensity. The focus of the first 10 - 15 years of the monitored period was on achieving a higher utilization of N in manure supplemented later by introduction of catch crops. During 2005 – 2015 the cover of catch crops increased from less than 1 pct. to 8 or 10 pct. of the cropped area depending on the amount of manure applied on a particular farm.

Statistical analyses in percolation weighted nitrate concentrations in root zone water from loamy and sandy catchments decreased by, respectively, 0.34 and 0.65 mg N L^{-1} during 1991-2015. At the same time, the measured flow weighted total N concentration in streams draining the five catchments has been reduced by 23-64 pct. Only part of the N leached from the root zone will reach the streams. The N retention (mainly denitrification) between the root zone and the stream outlet varies from 25 to 90 pct. within the individual catchment and depends on local conditions encompassing both geology and hydrologic pathways.

Knowledge gained in the Agricultural Monitoring Programme supports efforts on introducing targeted regulation to reduce agricultural N losses.

Nitrate leaching from new forests on arable land – short and long term monitoring

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Background and aims

One option to reduce N emissions to water is to afforest N-sensitive areas. In Denmark, part of the arable land in some sensitive groundwater catchments with limestone or sand aquifers has been afforested since the late 1990's. Recent changes in agricultural regulation and targeted subsidies to private landowners will likely increase afforestation over the coming years with the primary aim to reduce nitrate leaching. Former arable soils have accumulated large amounts of N in organic matter with low C/N ratio compared to soils with long forest history. The aim of this study was to investigate to what extent the legacy from the agricultural use will influence N cycling in new forests and to estimate the long term reduction in nitrate leaching from afforestations on arable land; i.e. to quantify the effect of afforestation as mitigation option. My hypotheses were i) that plant N demand control N leaching until canopy closure and keep the concentration low or close to zero; ii) after canopy closure plant N demand diminish and N leaching increase to a level depending on N deposition; iii) soil N accumulation will be minor on former arable land.

Methods

Soil water chemistry data from previous and ongoing monitoring in new forests on former arable land were compiled. Some sites were revisited to obtain soil for nitrate extraction and at other sites soil suction cups were reinstalled and monitoring resumed. Soil water nitrate concentrations were available for 8 afforestation areas and covered monitoring periods from 17 to 31 years. Time since conversion ranged from 0 to >50 years and for two areas data from chronosequences were available. Effects of soil preparation alternatives and tree species could be compared in some of the areas.

Results

High nitrate concentrations (50->100 mg/l) from the preceding agricultural use and from soil preparation or mechanical weed control declined to <10 mg/l within 3-5 years after planting. Canopy closed forest on nutrient rich soils had longer periods with nitrate concentrations >25 mg/l, where N-balances indicated a net loss of soil N. Thinning activities stimulating regrowth of both trees and ground flora and markedly reduced the nitrate concentration. On sandy and nutrient poor soils nitrate concentrations increase slightly with forest age but remained <10 mg/l. Tree species influenced the nitrate concentration with spruce having the highest concentration followed by beech and with lower concentrations in oak, ash and maple. Flux calculations are still in progress.

Conclusions

The agricultural legacy makes new forests prone to elevated N leaching compared to old forest, except on sandy nutrient poor soils where N may still accumulate in soil organic matter. On some nutrient rich sites there is a net loss of soil N over several decades after afforestation. Some tree species modify the N cycle; however this aspect needs further study. The vegetation N-sink is largely controlling the nitrate concentration dynamics, thus regular thinnings including whole tree harvest to remove N and to stimulate regrowth are important in managing new forest to reduce N leaching.

Atmospheric ammonia, ammonium and incident asthma - A nationwide case-control study in Danish preschool children

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Background

Particulate matter less than 2.5 µm in diameter ($PM_{2.5}$) has repeatedly been associated with respiratory illness. The role of particulate constituents such as ammonium is, however, less clear.

Objective

We investigated gaseous ammonia (NH_3), particulate ammonium (NH_4^+), the total concentration of these pollutants (NH_x), and total $PM_{2.5}$ and their association with asthma in Danish preschool children.

Methods

We used a register-based matched case-control design. Cases comprised children with first diagnosis of asthma from general practices or hospitals (n=12,948) from their 1st to their 6th birthday during 2006-2012. Per case, we selected 25 controls at random (n=323,700) having no asthma diagnosis and matched on sex and birthday. Modeled average concentrations of NH_3, NH_4^+, NH_x and $PM_{2.5}$ (5.6 km x 5.6 km grid resolution) during the last 3, 6 and 12 months prior to diagnosis were linked to registry data on residential coordinates, asthma diagnosis and covariate information.

Results

There was a positive association between NH_3 exposure (adjusted hazard ratio ((HR_{adj}, 95%CI) 1.74, 1.6-1.90), NH_4^+ exposure ((HR_{adj}, 95%CI) 2.33, 2.012.6), NH_x exposure ((HR_{adj}, 95%CI) 1.88, 1.69-2.09) and cases of asthma (3 month exposure time-window). The direction of these associations changed when adjusting for region and socio-economic status, but remained when NH_4^+ was adjusted for total $PM_{2.5}$. $PM_{2.5}$ exposure was not associated with asthma (HR_{adj}, 95%CI) 0.96, 0.86-1.1). Similar results were obtained for 6 and 12 months exposure time-windows.

Conclusion

NH_3 and NH_4^+ exposure may be risk factors of onset asthma in preschool children. Further prospective exploration in large-scale populations is needed to confirm the result and foreclose confounding.

Acknowledgements

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Nitrogen and agriculture in the Nordic countries - policy, measures and recommendations

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The Nordic countries have during the last 20 years, introduced efficient measures to reduce nitrogen losses to the environment. Still, N losses from the agricultural sector are high. Furthermore, projections indicate relatively small emission reductions in the coming years.

The aim of this study was to provide recommendations on:

i) Issues, strategies and policy instruments to achieve cost effective abatement of reactive nitrogen from agriculture in the Nordic countries,

ii) The need for further work to understand the nitrogen reduction effects of integrated, cost effective control strategies for reactive nitrogen in the Nordic countries.

This study is based on a literature review, and the outputs from a workshop held in Gothenburg in January 2017, with 11 participants from four Nordic countries (Sweden, Denmark, Finland and Norway) with different backgrounds within the field of nitrogen and agriculture. During the workshop we identified a number of policy challenges, policy actions and knowledge gaps where further research is needed.

We conclude that the main focus in the Nordic countries should be on implementing the most cost effective, practical and feasible measures. We recommend a holistic policy approach, not only considering the direct mitigating effect and costs of measures, but also other benefits and effects. We recommend that some of the current farm-regulations are simplified. In some cases we recommend extending current rules and regulations. We recommend advisory efforts with repeated farm visits, informing how measures relate to farm economy and feedback to farmers to encourage changed farming behaviour. We also recommend an information campaign regarding a change in consumption behaviour, highlighting the benefits both for the environment and health.

The main knowledge gap that we identified refers to the complex interactions, synergies and trade-offs between different pollutants and environmental effects. This complexity demands relevant assessment tools and more research to find the right balance between potential conflicting interests, including e.g. emission savings, ethical values, costs and other environmental effects.

This study was funded by the Nordic Council of Ministers (NMR) to which the authors are very grateful. Thank you also to the workshop participants for contributing with knowledge and interesting discussions during the Nordic workshop.

Generating EU-wide endogenous crop yield responses to nitrogen to predict the impact of environmental policies on farm-level cropping systems

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The 2013 EU Common Agricultural Policy (CAP) has put more focus on environmental sustainability of the EU agricultural sector. It is particularly interesting from an economic and nutritional perspective to predict how farmers may alter their cropping system when a policy change requires the reduction of a major agricultural input such as nitrogen (N). To enable EU-wide predictions, yield response curves were generated for each region at the 2nd level of the Nomenclature of Territorial Units for Statistics (NUTS-2). As NUTS-2 regions can be very large and therefore exhibit heterogeneous soil characteristics, we first divided each NUTS-2 region into existing homogenous soil mapping units (HSMU), for which soil characteristics are available from the EU Soil Database. Due to differences in soil organic matter content between arable land, orchard and grassland within each HSMU, we differentiated as well between these land use classes. Other soil parameters were calculated using pedotransfer functions. We then ran the EU-rotate_N model at HSMU level for different doses of organic manure and mineral N fertilizers, each time without and with irrigation, in amounts controlled by the soil water deficit. Target yields, which are maximum attainable yields required to run the EU-rotate_N model, were defined as the 90% quantiles of the EU Farm Accountancy Data Network for each NUTS-2 region. As a test-case, simulations were run and yield response curves were generated for soft wheat, barley, grain maize, oilseed rape, potatoes, sugar beet and permanent grassland in the NUTS-2 regions Andalusia, Calabria and East-Flanders. For each crop, average yield response functions at the NUTS-2 level were created by a weighted regression of all HSMU simulations with weights equal to the ratio between the crop area on HSMU level and the total crop area on NUTS-2 level. Regression was done between the yield and the applied inorganic and organic N using linear and quadratic functional forms. There was no distinct best fitted functional form over all crops and regions, but yield functions were more responsive to applied inorganic N than to organic N. Irrigation in Andalusia and Calabria increased potato yields up to 100% but had only a small effect on cereal yields, probably due to the early development of cereals under less dry conditions and resulting in deeper rooting systems. Taking into account the variation within each NUTS-2 region, comparison of the simulated yield response curves with site-specific field measurements from literature and simulated results from another model (CAPRI) did indicate that the overall output was reliable. However, we observed an overestimated response for grassland and potatoes in East-Flanders, while the response for wheat and potatoes was underestimated in the Mediterranean regions. Further calibration of the target yield will help to increase the accuracy of our results. Feeding the yield response functions to e.g. the EU Individual Farm Model (IFM-CAP) would enable to make combinations of yields and financial benefits and estimate the impact on a farm economic level. The chosen approach is therefore promising to contribute to a better assessment of the implications of new environmental policies on farm-level decisions across the EU.

Acknowledgement

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Nitrogen emission trading: a comparative study of the potentials

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Excessive nutrient loads from agricultural catchments is one of the main reasons for biodiversity degradation and eutrophication of marine and coastal areas in many different parts of the world. It has been widely argued that introduction of nutrient abatement policies that provide flexibility for farmers with respect to choice of abatement measure could significantly reduce the costs. Furthermore, flexibility to distribute the efforts between farmers is also very likely to reduce the overall costs of improving marine and coastal waters. One method to achieve such flexibility is a tradable nutrient permit scheme. Such a tradable scheme might be simply an introduction of a fixed cap on the total nitrogen loads and an allocation mechanism between polluters (farmers). A requirement for such a trade system to function and provide cost-efficient outcomes is a sufficient level of heterogeneity between farmers in terms of differences in costs. Another requirement for obtaining specific environmental quality targets at the coast is that the loads are reduced upstream from the specific coastal areas. This means that, reallocation of emission reductions must occur within the geographical boundary of the catchment. These two requirements might conflict as the last requirement might reduce the heterogeneity of the farmers.

In this study we compare the introduction of permit trade schemes in different agricultural landscapes; a sugarcane catchment in the Queensland region of Australia, and a mixed cereal and livestock agricultural catchment in the northern part of Denmark. The cases are chosen to be able to study and compare the effect of heterogeneity between farms on the incentives to trade, in terms of heterogeneity in land use, productivity and the resulting abatement costs. We apply the same spatially-specific modelling methodology of N-trading in the two catchments.

A participative network of organic and conventional crop farms in the Seine Basin (France) for evaluating nitrate leaching

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In the Seine Basin, characterized by intensive arable crops, most surface and groundwater is contaminated by nitrate (NO_3^-). A collaborative study was set up, involving a network of volunteer farmers, to investigate NO_3^- leaching with ceramic cups (90 cm deep) on whole crop rotations of organic (OF) and conventional (CF) commercial farms in the Seine Basin. A total of eight CF and six OF systems were studied (62 fields) in five different soil and climate conditions during 2 years, taking into account a wide diversity of practices (including low or no exogenous N inputs, systematic catch-crop implementation, and no tillage) and use of different exogenous organic matter (EOM) such as biogas residue; slurry; poultry manure; and cow and horse manure. Over the 2 years, OF cropping systems (including alfalfa) led to a lower average sub-root concentration 37 ± 9 mg $NO_3^-.l^{-1}$ than CF systems 48 ± 19 $NO_3^-.l^{-1}$, ± standard deviation between farms. The water inflows calculated ranged from 86 to 190 mm depending on the year for the 4-month drainage period. The amounts of nitrogen leached were on average 23% lower in OF (12.5 ± 2.9 kg N ha^{-1} yr^{-1}) than in CF systems (16.2 ± 6.3 kg N ha^{-1} yr^{-1}). Concerning farming practices, the main impacting factors were the use of EOM in fall, the lack of catch-crops before spring, and the proportion of legumes in the rotation. Overall, this wide collaborative network highlights good and innovative practices by CF and OF farmers attempting to decrease NO_3^- in groundwater.

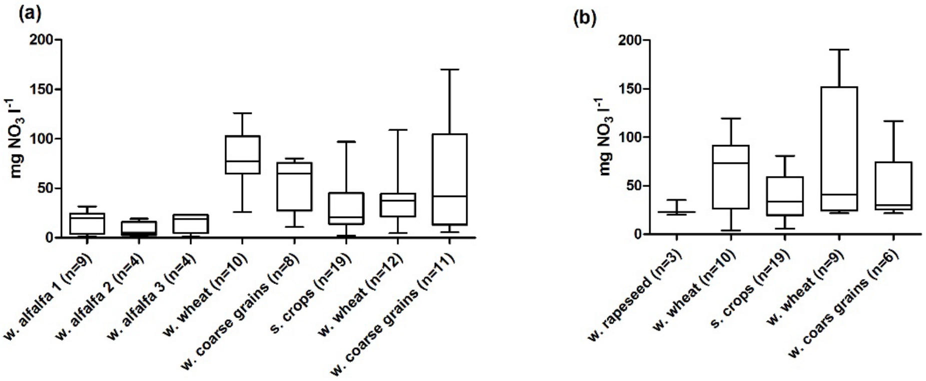

Figure. Median, minimum and maximum sub-root concentrations for the organic (a) and conventional (b) rotations for all the winter (w.) and spring (s.) crops pooled for the 2 years. Coarse grains are others than wheat, such as triticale, rye, oat, spelt, or barley. (n =) is the number of fields sampled during the two year for each crop.

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Reducing agricultural nitrogen loads through spatially targeting measures

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Reducing nitrogen (N) loads from agriculture to the aquatic environments in Denmark have so far been based on general measures to increase nitrogen use efficiency, but these have not been sufficient to achieve the environmental objectives without affecting agricultural production. Therefore, we addressed the possibilities of targeting measures to reduce N leaching losses to those parts of the landscape and agricultural systems, which contribute most to the N-loadings. This could be possible either through reducing the source N loading from the root zone or through enhancing the N retention/reduction in groundwater and surface waters. Spatially differentiated scenario analysis could be suitable tool for predicting future impacts under new N regulation in Denmark. Effectiveness of such analysis for agricultural N-load reduction to the aquatic environments could vary depending on the methods developed and used in the scenarios. In this study, a new method of spatially differentiated scenario analysis for two Danish catchments was conducted that reach across the individual farms in order to achieve the N-load reduction targets of 20% and 40%. It includes: (i) Relocation of existing agricultural practices based on the ground water and surface water N-reduction, (i.e. the ratio between the total N-load of the catchment and the N-leaching from the root zone for each spatial unit within the catchment) and considering available spatial/legal constraints (e.g. soil type and/or farm boundary). Accordingly, that crops/practices with high N-leaching were moved to areas with high N-reduction and vice versa. (ii) Cover crop(CC) application on potential areas within each catchment to decrease N-leaching, (iii) Set-a-side application on areas with high N-load. In this study, also two different scales of N-reduction (i.e. grid unit scale and sub-catchment scale) for analysis were used to compare and test the results of applying different scales of N-reduction maps on N-load reduction and extent of measures to achieve target reductions. For both catchments average N-leaching values for the period of 2000-2011 (agro-hydrological years) in grid unit scale were used. The data for soil type was based on the root zone database and the Information of crops for agricultural land on field scale for both catchments were based on the general farming register. In this way, 10 different scenarios were developed for each N-reduction scale. Overall, the results revealed that spatial constraints for N-leaching reallocation will affect the effectiveness of N-load reduction by spatially targeting measures, and where less constraints for spatial redistribution of nitrate leaching were considered, the highest N-load reduction and the highest reduction in set-a-side area were achieved. The results also showed that within each catchment a combination of land use, soil type, spatial variation in N-reduction and cropping conditions affect reduction of excessive N- loadings and the need for set-a-side area. Owing to this fact, the effectiveness of spatially differentiated measures based on different constraints for both N-load reduction targets in Odense catchment were greater compared to Norsminde catchment. Investigation of each scenario individually indicated using fine spatial N-reduction map is more effective compared to using sub-catchment scale N-reduction map in term of N-load and set-a-side reduction.

Developing local scenarios to nitrogen management using participatory planning – a practical perspective

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Since the 1990'ties it has been a central goal in Danish environmental policy to decrease nitrogen losses to the environment. Mitigation strategies have relied almost exclusively on a national top-down regulation, which outlines detailed requirements for farming practices. This approach has been very effective in reducing nitrogen losses to surface and ground water, as well as reducing ammonia emissions. While regulation in the 1990'ties was based on implementing good farming practices which increases nutrient utilization, additional regulation implemented after the turn of the century have incurred significant financial burdens on farmers, as well as restricting their freedom of operation on their farms. Over the last years, there has been a shift towards a targeted regulation that takes local conditions into account, in order to increase the cost effectiveness of mitigation strategies and to increase productivity where this is possible.

In this project, a participatory planning approach was tested in six local catchments in Denmark. In each catchment two workshops were held with broad representation of local stakeholders from local councils, municipal authorities, farmer councils and local farmers, anglers and local nature conservation societies. The aim of the first workshop was to collect suggestions for possible future scenarios for each catchment. Before the second workshop, suggestions and scenarios were consolidated into three thematic scenarios, which were visualized in a GIS based landscape scale decision support tool, and these three scenarios were discussed among stakeholders in the second workshop.

From an agricultural perspective the results of this process highlights that the stakes are very different between differing stakeholders in a local community. Since nitrogen cycling in rural catchment is dominated by farmland, farmers always play a central role in solution scenarios, both when scenarios concentrate on increasing agricultural production and when scenarios calls for reducing nitrogen losses from farming. In all cases, the farmer has much more at stake, than other stakeholders, since the scenarios directly affect farming economy. How this affect the local process is different in different catchments, because the farming community and the cooperation between stakeholders, is very different between the different catchments. Nonetheless, this disparity in stakes needs to be taken into account when involving a community in participatory planning regarding nitrogen management.

As part of a more targeted Danish regulation, a system of catchment officers is currently being established to aide in formulating mitigation strategies that are adapted to local needs and local landscapes. These catchment officers need to be acutely aware of the disparity in stakes between stakeholders in local communities.

The distribution of mineral nitrogen in soil in relation to risk of nitrogen leaching in farms with irrigated vegetables

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The region along lower part of Jizera River which empties into the Elbe River serves as an important source of drinking water for Prague (water works Káraný). Water is extracted by over 800 of bore wells supplied by water seeping from the river and the percolation, mostly from agricultural fields. The content of nitrate in the water has gradually increased in past years. The area belongs among the most important vegetable and early potatoes growing regions in the country. The production of vegetables often shows low N use efficiency and it is the source of excessive residual nitrate prone to leaching, especially under irrigation. The coexistence of the intensive vegetable production and water quality requirements is not easy.

The objectives of the study were to collect data on nitrate content and distribution in a soil and to evaluate the risk of nitrate losses by leaching from root zone in farm fields and to suggest agronomical measures to reduce the losses.

Methods and Materials

The content of soil mineral nitrogen (N_{min} = N-NO_3^- + N-NH_4^+) was monitored in 22 farms in years 2013-2016. Content of N_{min} and soil moisture down to 120 cm were determined at the end of winter or early spring, at about harvest and on the onset of winter. The risk of nitrate leaching during winter was evaluated from nitrate and water content and distribution in soil profile at autumn, precipitation and water balance, field water capacity of soil layers, and indication of depletion zone based on root depth of the cultivated species

Results

The average mineral nitrogen contents in fields ranged in experimental years and seasons from 91 to 157 kg N.ha^{-1} in 0-120 cm soil layer, 80-90 % of which in nitrate. Average N_{min} content in 0 - 60 cm zone, available for most crops, ranged in years from 52 to 85 kg N.ha^{-1} while only slightly lower content was found in 60 - 120 cm subsoil layers. The data suggest a high risk of nitrate losses from root zone of many vegetables but low precipitation reduced the risk.

Conclusions

The data showed the risk of nitrate leaching has to be evaluated according to several factors, not only the cultivated species. The indicators include the distribution of nitrate in soil, soil water capacity and water content of soil layers in autumn, root depth of cultivated crops and their demand for N. Standard determination of mineral N content in top and subsoil layers and introduction of crops with deep root systems (e.g. cereals) remain effective tools for N management. However, parallel study of hydro-geological conditions in the region proved that significant portion of water also comes from far sources (Czech cretaceous basin) with water accumulated in previous years and decades. Really effective measures aimed at future water quality need to reduce nitrogen losses in wider background of water accumulating area.

Acknowledgement

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The meat dogme project: exploring nitrogen mitigation in Denmark

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Reduction of meat consumption in Denmark – a country with a high production meat industry – is often stymied by a traditional and socially based support of the heavy meat diet.

Our research analyzes social themes which are pertinent for developing custom-based strategies aimed at reducing the current high level of meat usage. We have combined environmental science and philosophy in a transdisciplinary approach in our analysis and our fieldwork.

Our first study utilized a 'point of honor' commitment to a personal *dogme* of meat reduction. During a four-week reduction period, a small group of voluntary participants kept a food record and wrote journal entries of any personal or social impact from the process. Since they were at times duty-bound to refuse to eat meat, some participants found themselves in awkward social situations.

Our second study replaced the self-challenge with a small but involuntary meat-reduction in the weekly luncheon menu for a large group of young children at a daycare center, in cooperation with parents and staff members. We have observed that dietary changes can meet with more support from the affected group if they are initiated with a popular ceremony of commensality, such as a samples tasting day for the children's families.

Preliminary results for our second study suggest an average 20 % reduction in the institutional nitrogen (N) "foodprint" part of the N-footprint after the four-week period. For our third study, we plan to introduce the same kind of four-week meat-reduced luncheon menu in an institutional canteen for adults. Recording baseline data and data from a dogme period at an adult institution will enable us to compare various aspects of the N-footprint.

Integrated approaches for improving crop nitrogen use on dairy farms

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Background and Aim

Attempts to improve crop N use efficiency often meet with limited success and sometimes with unintended consequences. Here we describe a multilateral approach to improve capture and utilization of N by crops on dairy farms. We describe two ongoing studies: to reduce feed imports by improving crop yield and land allocation, and to reduce fertilizer imports with better manure use.

Methods (field studies and modelling)

Study 1. We compare current forage practices with delayed harvesting of early and late maturing grass varieties. The field crop results are modeled to balance feed rations and maintain milk production and to better allocate the proportion of land for grass and corn, in order to reduce feed imports. Study 2. We are evolving strategic manure practices with separated slurry, manure trading, and a nitrification inhibitor, and in future, managing manure using real-time models with short and medium term weather forecasting,

Results

Delayed harvesting increased grass nutrient yield and N capture, but lowered feed quality especially in early maturing varieties. Compared with conventional practices (5-cuttings of early maturing orchardgrass), the 3-cut late tall fescue variety produced 20% more herbage and captured 15% more N, probably due to a deeper roots and more leaf area for transpiring. A dairy feed model suggested that milk yield can be maintained with similar supplemental ingredients by substituting some of the lower quality grass with corn silage. The overall system is advantageous because: 1. 20% of grass land could be allocated to corn which has a higher energy yield, 2. corn can be double-cropped with protein-rich Italian ryegrass, 3. ryegrass effectively scavenges soil N after corn harvest and protects soil overwinter, 4. likelihood of better harvesting weather for preserving feed quality of the important first cut, 5. less labour overlap between planting corn and harvesting grass, 6. fewer field operations over the year. We estimate 10% of farm land can be freed up for planting more protein, energy or cash crops.

The second study demonstrated improvements in crop response to slurry manure nutrients after passive separation (settling), by band-applying the high-N liquid fraction to grass and precision injecting the high-P sludge in corn. We are now working to mitigate nitrous oxide emissions, and to exploit abundant poultry manure for N with a three-sector manure swap. Both projects are progressing well and new work is starting on real time manure management using short and mid-term weather forecasts. Overall we anticipate that N leakage from fields can be mitigated, but the conserved N must reduce crop and farm inputs to prevent pollution swapping. We established a semi-virtual farmlet trial to challenge these results in a system.

Conclusion

Muti-facted approaches are needed so that modest improvements, in aggregate, are meaningful, and integrated studies are needed to ensure that the gains are real and without unacceptable side-effects. We propose combined management of crops and nutrients while being fully mindful of optimizing performance of animals, whole farm and even multi-farms.

Controlled traffic farming increases crop yield, root growth and soil mineral N in organic vegetable production

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Background and aims

Problems of machinery induced soil compaction are evident in organic vegetable production, resulting in nitrogen (N) run-off, stunted root growth and reduced yield. Controlled traffic farming (CTF) uses GPS signals to keep machine traffic in permanent lanes. This restricts soil compaction to wheel tracks and creates traffic-free vegetable beds with improved soil structure. The aim of this study was to investigate the effect of CTF on soil mineral N, vegetable crop and root growth under organic management.

Methods

A field experiment was established from 2013 to 2016 at Skiftekær, a commercial organic vegetable farm on the island of Tåsinge in Denmark (sandy loam; precipitation 800 mm year^{-1}; average temperature 9.3 ºC). White cabbage (Brassica oleracea), potato (Solanum tuberosum) and beetroot (Beta vulgaris) were grown under CTF and random traffic farming (RTF), which served as the control. Soil mineral N, crop yield and root growth (minirhizotron method) were measured in 2015.

Results

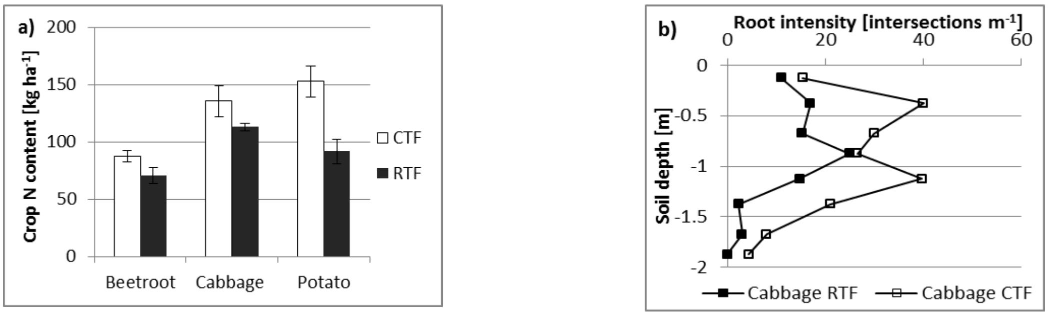

Figure 1.a) Crop N content and b) root distribution of cabbage at harvest to 2 m depth. RTF= random traffic farming; CTF= controlled traffic farming.

Conclusions

Results show that soil mineral N was higher in CTF for all crops in the spring and for beetroot and potato at the harvest (data not shown), indicating a higher availability of N in the CTF system. More N could therefore be taken up by the crops, as seen in the higher crop N content in CTF compared to RTF (Figure 1a). This effect was enhanced by the higher root intensity of cabbage in CTF compared to RTF (Figure 1b), indicating a better soil structure in this system. Marketable yields were 23-70 % higher in the CTF system.

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Catch crop with legumes can reduce N leaching and increase productivity in organic systems

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Background and aims

Catch crop (CC) is a valuable tool to reduce N leaching during the autumn. Mixtures of legumes (L) and non-legumes (NL) have the potential to both reduce N leaching and enhance N supply to the following crops. The aim of this study was to evaluate to which extent inclusion of legumes in catch crop mixtures could benefit organic systems in terms of N leaching and productivity.

Methods

Pea-barley, spring wheat and spring barley were grown as part of a crop rotation experiment in Foulum, Denmark, from 2011 to 2014. Four treatments were used: conventional with non-fixing CC and mineral fertilizer (C4/+CC/+F), organic with/without CC and manure (O4/+CC/+M, O4/+CC/-M, O4/-CC/+M). Ceramic suction cups were installed in all the plots at 1m depth; water samples were analyzed for nitrate content and the EVACROP model was used to calculate drainage and thus N leaching. CC samples were taken in November for DM and N analysis. BNF was estimated with the model by Høgh-Jensen et al. (Agric. Sys 2004, 82, 181-194) assuming Ndfa of 90%.

Results

N uptake in CC above-ground biomass was similar between C4/+CC/+F and O4/+CC/+M, and this also applied to N leaching (Table 1). N in CC tops was significantly higher in O4/+CC/-M, mainly due to a higher BNF, while N leaching was lower. In the organic system average N yield across the three crops was lower in O4/+CC/-M compared to O4/+CC/+M, but not significantly different from O4/-CC/+M; the latter having higher N leaching than the other two organic treatments (Figure 1).

Table 1: Average N content and BNF in CC above-ground biomass, and average N leaching (kg N/ ha y) the C4 and O4 treatments (n=18). In C4 CC are NL, in O4 mixture of L and NL.

	C4	O4	
	+CC/+F	+CC/+M	+CC/-M
N in CC	24 a	28 a	44 b
BNF in CC	-	11 a	26 b
N leaching	25 a	29 a	19 b

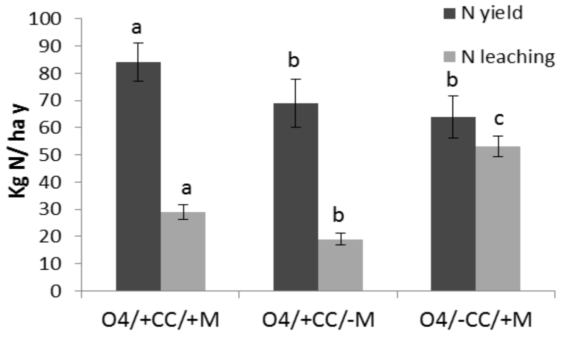

Figure 2: Average crop N yield and N leaching in the three organic treatments. Bars show standard error (n=18).

from
a

Conclusions

In the organic system studied here, a mixture of L and NL as CC significantly reduced N leaching and provided extra N to the following crop. BNF was highest in the treatment without manure.

Acknowledgement

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The suitability of organic residues as agricultural fertilisers in a circular economy

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Background and aims

The 2015 European Commission action plan for the 'Circular Economy' detailed proposed changes to the EC fertiliser regulations to include recognition of waste-based fertilisers in order to stimulate an EU-wide market in trade of such products (European Commission 2015). Recent increases in fertiliser prices, and an increasing interest in recycling organic wastes, recovering and reusing the nutrients and organic matter as bio-based fertilisers, have made new types of waste residuals more commercially relevant to farmers, including those from urban settings (municipal household waste, sewage treatment sludge) and food or biomedical industries (e.g. sludges from production of enzymes, potato starch etc.). Furthermore, processing of some of the standard organic waste residuals using novel treatment techniques (such as biogasification, composting, mineral precipitates from waste waters, or incineration, gasification or pyrolysis of sludges and other solid wastes) produce residuals with new properties. There is a lack of knowledge as to whether further processing could make these residues more valuable as bio-based fertilisers, due to enhanced nutrient release or availability.

Methods

This study screened 15 different organic residues including manures, digestates, sludges, composts and struvites, and compared their release of mineral nitrogen (N) and phosphorous (P) following addition to soil. Following this, three of the residues with potential for improvement were modified using heat & pressure (105 °C at 220 kPa), alkalinisation (pH 10), or sonification to try to improve N and P release properties.

Results

Nitrogen and phosphorous release properties varied widely between residue types. Generally, maximum N release was negatively correlated with C:N ratio of the material (r=-0.6). Composted, dried, or raw residues had a lower N release (mean of 10.8 ± 0.5, 45.3 ± 7.2, 47.4 ± 3.2 % of total N added respectively) than digestates, industry fertiliser products, and struvites (mean of 58.2 ± 2.8, 77.7 ± 6.0, and 100.0 ± 13.1 % of total N added respectively). A number of organic residue sources from this second category in particular have potential to be used as agricultural N fertilisers competitive with mineral fertilisers. Phosphorous release as water extractable phosphorous was much more variable, and no single chemical property or processing type could explain differences in P release. No single upgrading treatment consistently increased N or P supply from the dairy sludge or the two biosolids. However, for one raw biosolid type, heating at a low temperature (105 °C) with pressure did increase N release as a percentage of total N added to soil from 30 to 43%. There was not significant difference in P release between raw and upgraded treatments.

Conclusions

Digestates, industry products, and struvites appear to be effective at providing N following addition to soil. Further research is required to investigate suitable upgrading methods to improve raw / anaerobically digested organic residues in order to improve N and P release, and heating at a relatively low temperature (105 °C) with pressure should be one of these methods considered further.

Acknowledgements

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A comparison of disaggregated nitrogen budgets for Danish agriculture using Europe-wide and national approaches

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Background and aims

Spatially detailed information on nitrogen (N) budgets is relevant to identify biophysical regions with a high need to significantly reduce N pollution in view of the implementation of the Water Framework Directive and the Nitrates Directive. Moreover, for regional policymakers, there is a need to disaggregate national budgets to the scale of administrative regions responsible for e.g. health and business development, and of municipalities responsible for e.g. local environmental regulation. However, the availability of consistent reliable spatially explicit input data is generally lacking. Therefore most models applied in Europe use national scale data as model input. In this study we investigated the reduction in uncertainty in spatially explicit N budgets for Denmark by comparing high and low resolution input data available at national and European scale, respectively.

Methods

Spatially disaggregated agricultural N budgets for Denmark for the period 2000-2010 were generated by the European scale model Integrator, being fed with high spatial resolution national data for Denmark (Integrator-DK) and compared with results obtained by using the default data (Integrator-EU). In Integrator-DK, we used the boundaries of Danish municipalities being more detailed than the boundaries in Integrator-EU and we used detailed Danish data on the crop types, livestock types and fertilizer application rates.

Results

Results show that clear differences exist for national and regional budgets calculated by both versions of the model. National N budgets calculated by Integrator-DK differ by about 10% with the Integrator-EU results. A comparison with an independently derived Danish national budget for the year 2010 showed that the Integrator-EU performed better. However, the spatial distribution of manure distribution and N losses from Integrator-DK are closer to an expert judgement assessment than those from Integrator-EU.

Conclusions

The incorporation of detailed national data rather than less detailed European data does not necessarily result in more reliable national N budgets. The results, however, indicate that the quality of European scale model results is much better at national scale than at regional scale (NUTS3 and municipality level) within countries.

Spatial and time variations in agricultural loss of nitrogen to 44 small Danish streams – 1990-2015.

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The huge reduction in the diffuse nitrogen (N) load to surface waters in Denmark during the last 25 years is in general strongly related to the reduction of the N surplus and hence the N leaching from agricultural land. N concentrations and loads have been monitored since 1990 (1-64 km^2; >60% farmed land) in 44 streams draining small intensively farmed small catchments with only minor sewage outlets. This monitoring aims to contribute to an evaluation of the outcomes achieved of the mitigation measures taken to reduce the agriculturally derived N emissions to Danish surface waters.

The inter-annual variations in the measured N load to the monitored streams arefound to be related to variations in precipitation and freshwater discharge, and when normalising the measured N loads based on mean annual runoff a 44% (median) reduction in the N load was determined for the period 1990-2015. However, catchment-specific reductions exhibit strong variations (6-64% as a downward trend). These variations are, among other factors, related to the difference in N reduction in anoxic/anaerobic aquifers during the transport of N from soil to surface water. Another main factor influencing the annual N load is the annual runoff taking place during the winter period (Dec. – Feb.) where N concentrations in drainage water generally are high. Finally, also the winter temperature influences the overall N loss to surface waters. Hence, in order to evaluate the general effect of mitigation measures taken to reduce the diffuse N load from agricultural land it is necessary to include corrections for inter-annual variations in runoff as well as for the influence of varying winter temperatures and runoff.

A new method for normalising the nitrogen load will be presented together with the outcome of a trend analyze exploring long term trends. Also the possibilities of including and correcting for time lag will be discussed.

High resolution modelling of N-retention in a restored riparian wetland

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Riparian wetlands improve the recreational value of rivers, biodiversity and water purification, and provide flood protection, shoreline stabilization, groundwater recharge, and streamflow maintenance. In Denmark, wetland restoration is used to improve riparian and channel habitats and to reduce nutrients loads to Danish streams and fjords. When considering river and wetland restoration, there are tradeoffs (and synergies) between the needs for flood protection, and climate change adaptation, farming productivity and freshwater ecology. Channelization and agricultural drains improve land drainage, increase productive areas and control flooding. Conversely, wetlands provide nature-based solutions for urban flood resilience and reduce nutrient loadings through processes such as sedimentation and de-nitrification/nitrification processes. It is therefore important for nutrient and flood management to be able to simulate the hydrological, ecological and environmental functioning of natural, restored and artificial wetlands.

The aim of this study is to present the development and evaluation of an integrated flow, water quality and ecological model, capable of representing flow and nitrate processes in riparian wetlands at the landscape and catchment scale, including the effects of physical alterations such as channelization and agricultural drains. The ability of the tool to represent actual wetland conditions has been evaluated against field observations obtained from a restored riparian wetland on the Odense River in Denmark. The initial simulations show that this tool is able to capture the observed flows in the groundwater, river and wetland system. Simulations of the same area prior to restoration, with channel straightening and tile drains can be used to quantify the effect of restoration on flooding behaviour, which is important for both flood protection and the wetland ecology (Figure 1.) as well as nitrate retention. Using a relatively simple description of the nitrate processes, we were able to estimated nitrate reductions from restoration comparable with other recent studies in Danish wetlands.

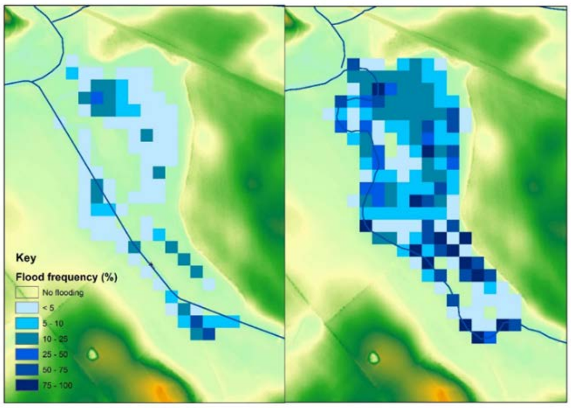

Figure 1: Comparison of the flood distributions before (left) and after (right) restoration.

How green are your pastures? Variations in nitrogen content of grazed forages on dairy farms in Australia

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Background and aims

Declining nitrogen (N) use efficiency is an increasing challenge in intensifying grazing-based dairy systems (Stott and Gourley 2016). Excess N intake results in increased N concentrations in dairy cow excreta, with implications for N leaching and gaseous losses. Acquiring data on N concentrations of grazed forages and accounting for variations due to seasonal conditions and N fertiliser applications is important to more accurately determine N intakes and excreta N loads, and improve predictions of N recycling and losses within grazing-based dairy systems (Aarons *et al.* 2016).

Methods

Grazed forages to be consumed by cows were identified on 44 contrasting dairy farms from all major dairy regions in Australia and sampled on 5 occasions over a 15 month period. Perennial ryegrass was the most dominant grazed forage, although a range of home-grown forages were present. Additionally, pasture samples were collected from a series of urea fertiliser studies on 3 dairy farms, where applied N rates ranged from 0 - 160 kg N/ha. Crude protein (CP) concentrations were determined using near infrared spectrophotometry.

Results

The mean CP concentration for the different grazed forages ranged from 13.1 - 29.4%, with turnips the lowest and lucerne the highest. Perennial ryegrass based pasture was the predominant forage on offer with CP concentrations ranging from 6.1 - 35.3%. While this diversity is not unexpected considering the large sample numbers and variety of dairy farm systems sampled, 50% of the CP data were within a relatively narrow range (Fig. 1).

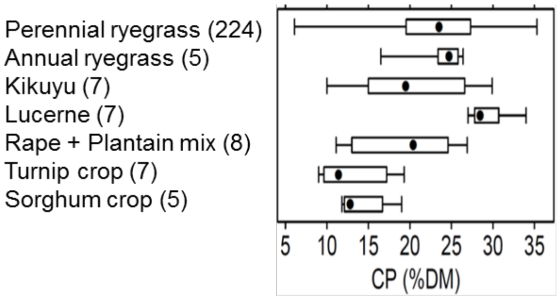

Figure 1. Box and whisker plots of crude protein content for grazed forages collected from 44 commercial dairy farms.

There was a significant difference in CP% of perennial ryegrass between seasons ($P<0.001$) with average Winter, Spring, Summer and Autumn values of 25.3, 19.1, 16.8 and 23.3, respectively. While CP% did not differ between dairy regions alone ($P=0.117$), there was a significant region x season effect ($P=0.037$).

Increasing N fertiliser rate significantly increased pasture CP% as well as DM yield ($P<0.001$) at all 3 field sites and each of the 5 measurement periods. Increases in CP% between the 0 and 160 kg N application ranged from 7.5 - 11.9%, while between the 0 and 40 kg N/ha application (average farm application rate) the range was a more modest 1.7 - 3.5%.

Conclusions

These results demonstrate the significant influence of seasonal conditions and fertiliser N applications on CP% of grazed forages and provide refined estimates of CP intakes within these farming systems. However the largely unexplained 'between-farm' variation suggests more comprehensive research is required into environmental and management influences on forage CP%. Further, research exploring relationships between N intakes, excreted N (particularly urinary N) and milk urea N concentration, at the individual cow and whole herd scale, may provide more reliable indicators for optimising dairy cow N intakes.

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Nitrate in drinking water and colorectal cancer

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Background

Nitrate in drinking water is suspected to cause colorectal cancer due to endogenous transformation into carcinogenic *N*-nitroso compounds. Epidemiological evidence is limited, previous studies were often challenged by estimating long-term exposure on an individual level.

Methods

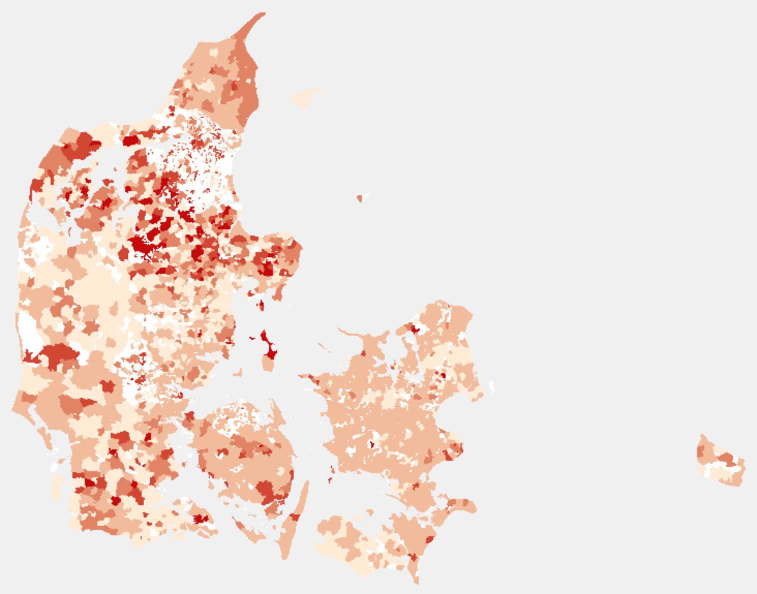
We exploited longitudinal population-based data on health and drinking water quality to study the impact of nitrate in drinking water on colorectal cancer risk. We calculated nitrate exposures for the entire Danish population, based on water quality analyses in public water supply areas and private wells between 1978 and 2011. Follow-up started at age 35. We used Cox proportional hazards models to estimate hazard ratios (HRs) of nitrate exposure quintiles and a trend-summary statistic adjusting for potential confounders.

Results

Results from this Ph.D. project under the dNmark research alliance will be presented. In short, we found a positive association between nitrate in drinking water and hazard of colon cancer for both sexes and females, and a not statistically significant association for males. An increased hazard was found for the highest exposed quintiles for both sexes and females below the current drinking water standard.

Conclusions

Our results add to the body of evidence suggesting an increased risk of colon cancer at nitrate concentrations in drinking water well below the current drinking water standard. A discussion on the adequacy of the drinking water standard in regards to chronic effects is warranted.



The nitrogen footprint – environmentally relevant?

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Background and aims

The nitrogen (N) footprint has been proposed as a tool to highlight and quantify contributions to N-related damages to the environment and to human health [1, 2]. It may succeed in raising awareness of consumers and decision-makers, not least due to its seeming simplicity and its catchy name, familiar from siblings like the ecological, carbon, and water footprints.

However, the family of footprints has been called a “minefield” [3] since their definitions have been incoherent and inexact, leaving room for confusion and contradictions. Therefore, a task force of the UNEP-SETAC Life Cycle Initiative has proposed some common ground rules for footprints [4], for example a set of four criteria for footprints: (1) transparent documentation, (2) accurate terminology, (3) directional consistency, and (4) environmental relevance. Here, we consider how well the N footprint lives up to the latter two of these.

Method

The two criteria are defined as follows [3]. Environmental relevance is that the footprint units have “environmental equivalence”, i.e., that each unit of footprint is considered equally harmful. Directional consistency is when “a smaller value is always preferable to a higher”. The N footprint is defined [1] as “the total amount of Nr [reactive N, all other forms than N_2] released to the environment as a result of an entity's resource consumption”. We evaluated how well the N footprint satisifes the two criteria by examining examples from agriculture.

The type and amount of damage an Nr molecule causes on its path through the N cascade depends on where, when, and in what chemical form it is released. For example, one product may be heavy in gaseous ammonia (NH_3) emissions, and another in leached nitrate (NO_3^-). Local conditions then determine how the Nr is transformed, deposited, taken up by plants, etc, and in turn how the environment is affected, for example, whether critical loads are exceeded. This illustrates that a given amount of Nr release may cause very different combinations of acidification, eutrophication, climate change, etc. Furthermore, the relative importance of these damages is not set in stone, but ultimately a question of values.

Results and conclusions

In summary, we suggest that the N footprint definition does not guarantee environmental relevance or directional consistency. Two products can have equal footprints but qualitatively different environmental effects. Which product to prefer then depends both on situation-specific details and the values held by the footprint user. We will present examples to illustrate these problems, and discuss possibilities to further develop the N footprint to address them.

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The environmental benefits of plant-based diets contested: the nitrate footprint of agricultural commodities compared

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Background and aim

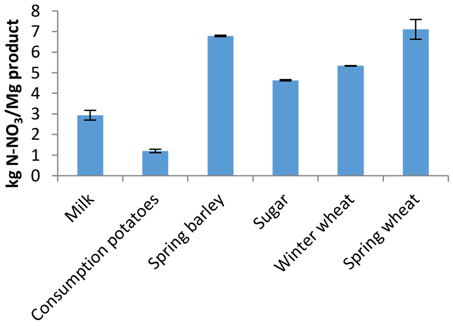
Plant-based diets are increasingly being promoted because of human health benefits and reduced environmental impact (Wellesley et al., 2015; Ocké et al., 2017). In the Netherlands, the livestock production sector is characterized by a high livestock density associated with large manure surpluses which put pressure on both air and water quality. A recent pilot study, assessing the effects of vegetable cropping on sandy soils, showed that nitrate concentrations in the upper groundwater were in the order of 200 mg NO_3 l^{-1} which is about six times as large as concentrations found under permanent grassland (Hooijboer et al., 2014; Hoogsteen et al., 2016). We questioned the environmental benefits of plant-based versus animal based products and compared the nitrate footprint of different agricultural commodities produced in the Netherlands.

Methods

Since 1992, Dutch Minerals Policy Monitoring Program is in place, which measures the effects of manure policies on water quality (Fraters et al., 1998) on around 450 farms. All farms are sampled annually and 16 subsamples are taken of the upper meter of groundwater. The nitrate concentration is measured in the field. Data on farm management and production characteristics such as yields of fodder crops and milk are also collected. Nitrate concentrations were linked with crop type through an overlay with data from the national farm survey for the period 2009-2014 (Statistics Netherlands, 2017). Average yields were obtained per crop type from Statistics Netherlands (2017) and from the sampled farms in case of fodder crops. The NO_3 footprint was calculated by dividing the NO_3 concentration (expressed in kg N-NO_3/ha) by the national average yields. For milk, the external input of concentrates (under the assumption that 100% of the concentrates consisted of cereals) was also taken into account. Yields of sugar beets were converted to sugar using a factor of 0.13 (FAO, 2009)

Results

The nitrate footprint of cereal crops is about twice the footprint of milk. Lowest footprints were found for potato which is a consequence of its high yield. I.e. the average yield of potato was 51 Mg/ha with an NO_3 flux of 62 kg N/ha leaching to the groundwater, while the average yield of spring wheat was 7 Mg/ha with an NO_3 flux of 51 kg N/ha.



Conclusions and outlook

The N-NO_3 footprint of cereals is much higher as compared to milk. For this reason one could question the environmental benefits of vegan diets with respect to water quality (i.e. replacement of animal protein by wheat protein). Future research will focus on expanding the footprint to an N-footprint by including the emissions of ammonia and N_2O. Furthermore, the effects of soil type and depth of groundwater table will be studied.

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How can we remove accumulated nitrogen by use of farming systems in order to protect our groundwater?

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In Aalborg, Denmark the Authorities has designated a zone around the wells in the catchment area where the leaching maximum from the root zone is limited to 25 mg nitrate/l. The purpose of this zone called the vulnerable zone is to insure that the nitrate content in the drinking water does not exceed the drinking water standard (50 mg nitrate/l). The extent of the vulnerable zone depends on the actually land use and it is used where the geology show vulnerability towards nitrate.

The restriction of 25 mg nitrate/l is harsh, but it keeps the extent of the vulnerable zone as small as possible and thus affect fewer landowners. The alternative is a restriction on 50 mg nitrate/l in all of the catchment area.

The protection measures works! Large areas now covered with restrictions starting to show an improvement in the groundwater quality. However the land use possibilities with a leaching restriction on 25 mg nitrate/l is limited to fallow, grazing areas with a confined number of animals, afforestation with deciduous trees. In our experience, none of these measures is immediately attractive to traditional farmers.

This raises the question: How can we unite groundwater protection and a high recharge with an attractive land use for active landowners?

Afforestation is an accepted cost-effective measure to protect the groundwater with several positive side effects like CO_2-binding, recreation and public health, biodiversity etc. numerous compliant to the UN Sustainable Development Goals.

In cooperation with scientists and the municipality (forest owner), we have been monitoring the nitrate content in soil water on three separate locations with grazing and afforestation since 1999. In periods these results has shown leaching well above 50 mg nitrate/l from the afforestation area on former agricultural land, which is NOT the case in other areas and hence not expected.

Therefore, we have decided to repeat the investigations in the connection with designed afforestation on a new former agricultural land in the spring 2017. We have expanded our original partnership with a forest entrepreneur and we have in our up-coming forest design focus at the choice of tree species, the soil preparation and cleaning methods around the trees the first years.

However, we realize that we need knowledge about how to reduce the accumulated nitrogen in the root zone. As an example, we know that without application of fertilizer, fast growing energy crops with a high harvesting frequency like willow can remove nitrogen. Unfortunately, this also reduces the groundwater recharge severely. Is that an acceptable temporary measure? Or is it possible to identify other kinds of farming systems, to reduce accumulated nitrogen from the system?

In our previously approach we have not allowed a yield-giving operation in the vulnerable zone. The present knowledge however, clearly indicate that it is necessary to remove nitrogen, by some kind of farming system. By that, perhaps we can make groundwater protection an attractive measure for the landowners.

Inclusion of nitrification inhibitor in animal feed to reduce environmental N losses

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Introduction

In grazed pastures, urine patches are the main source of nitrate leaching and nitrous oxide loss to the environment. Nitrification inhibitors such as DCD have been shown to reduce these losses by up to 80%. Use of inhibitors to treat urine by broadcast spraying across grazed pastures is expensive. However, there is a potential to target DCD in urine patches by inclusion of the inhibitor as a feed additive, thereby reducing costs and the amount required.

Methods

We investigated the efficacy of feeding cows with DCD (mixed with supplementary feeds) to achieve targeted delivery of DCD to urine patches and to test the effects on N_2O emissions. Three groups of cows (n=5) were fed daily one of three treatments (3kg of grass silage GS, maize silage MS or barley concentrate BC) that had DCD (30 g cow^{-1}) manually mixed with it. Cows were rotated through the treatments in a Latin square design. Cows were pre-conditioned with their feeds and then grazed. Urine patches were sampled, soil extracted with KCl, DCD analysed by HPLC. Urine was collected from cows fed with DCD amended feeds and frozen. This urine (2L and equivalent to 30 kg DCD rate) was then applied in spring and autumn, and compared to control urine (no DCD) and N_2O emissions were measured using the static chamber method.

Results

The mean DCD application rates within urine patches from the three feeding treatments varied between 25 and 40 kg ha^{-1} but there was no significant treatment effect ($P > 0.05$). Urine DCD and total nitrogen concentrations were significantly positively correlated (Minet *et al.* 2016). Cumulative N_2O emissions from urine plots were significantly reduced with DCD from 5.32 to 2.53 kg N_2O-N ha^{-1} in spring and 8.71 to 3.34 kg N_2O-N ha^{-1} in autumn. Amending animal feed with DCD reduced the urine N_2O emission factor from 0.7 to 0.27% in spring and 1.07 to 0.37% in autumn.

Conclusions

This experiment shows that supplementing any of the three feeds with DCD should be similarly effective at delivering high DCD rates to urine patches where high N levels can lead to large N losses. The inclusion of DCD in animal feed significantly reduces N_2O emissions from urine applied in spring and autumn. DCD could easily be incorporated into animal feeds and would reduce costs compared with DCD blanket application, as well as decreasing N losses to air and water.

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Acknowledgements

Funding was provided by the New Zealand Government to support the objectives of the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases (MPI/AgResearch Contract No. 15811). Any view or opinion expressed does not necessarily represent the view of the Global Research Alliance. DCD use in New Zealand is restricted to research. Protocols to ensure that DCD use in research does not enter the food chain are supported by soil and plant testing for DCD residues.

Diet management to effectively abate N_2O emissions from surface applied pig slurry

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Background and aims

Compounds such as hippuric and benzoic acid present in urine/slurry can be controlled through diet manipulation to mitigate nitrous oxide (N_2O) when these urine/slurries are applied in the soil. This study evaluates how the inclusion of fibrous by-products onto pigs' diet affects the concentration of organic acids in the excreted urine/slurry, and how these changes can affect soil gas emissions.

Methods

Slurries were obtained from growing-finishing pigs fed with five contrasting diets: a conventional diet (pig slurry control, PSC); orange pulp and carob meal at a dietary fiber level of 75 or 150 g kg^{-1} (OP-75; OP-150; CM-75; CM-150) and were then used as fertilizer in grassland meso-cosms. A control treatment without slurry was also included. The N_2O emissions were measured using static chambers following slurry application, alongside measurements of ammonium (NH_4^+), nitrate (NO_3^-), and dissolved organic carbon (DOC) in soil.

Results

Soils amended with slurries obtained from fibre by-products, OP and CM, decreased N_2O emissions by 65 and 47%, respectively, compared with slurries coming from a conventional pig diet. Benzoic acid was negatively correlated with N_2O emission for OP slurries, which doubled the hippuric acid content, and presented 1.8 times more benzoic acid than the CM. However, this effect only occurred during the first week following application due to rapid degradation of this compound within the soil. The possible toxic effect of benzoic acid did not appear to impact on soil respiration, since a positive correlation was found. The balance of benzoic acid (considering both intake through feed and release through urine) indicated that the source of both acids were phenolic compounds (polyphenolic or lignin) present in the fibrous fraction.

Conclusions

These results show that gas emissions are strongly related to compounds within urine/faeces that can be manipulated indirectly through the diet thus offering a highly effective GHG mitigation strategy which also enhances reusing of by-products of Mediterranean agroecosystems in a circular economy based approach.

National Nitrogen Budgets from 1965 to 2010 for 212 countries

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Nitrogen budgets provide the data basis for understanding past dynamics of the nitrogen cycle and to create forward-looking scenarios. However, many nitrogen flows cannot be measured directly, but have to be estimated indirectly; moreover, limited data exists for many developing countries, and national budgets cannot be easily compared.

Here we present consistent national nitrogen budgets for 212 countries for 11 time slices between 1965 and 2010, including detailed cropland nitrogen budgets and nitrogen flows from fixation to crop production, processing & livestock, to consumption and emissions. Our method innovates in

- Providing an open-source software package in R that can automatically download and processes data and that is programmed in a functional way that allows easy inclusion of new flows and updated data.
- Detailed nitrogen budgets using an updated methodology of Bodirsky et al (2012)
- Full consistency with FAOSTAT and IPCC Guidelines for National Greenhouse Gas Inventories, while further disaggregating flows, e.g. in the livestock sector (e.g. feed distribution between animals) and processing (e.g. sugar, ethanol, oil)

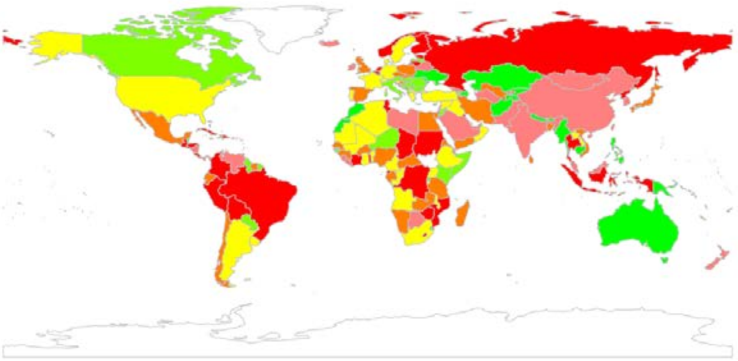

Fig1 (top): Estimated cropland soil nitrogen uptake efficiency in the year 2010 (red:low, green:high)

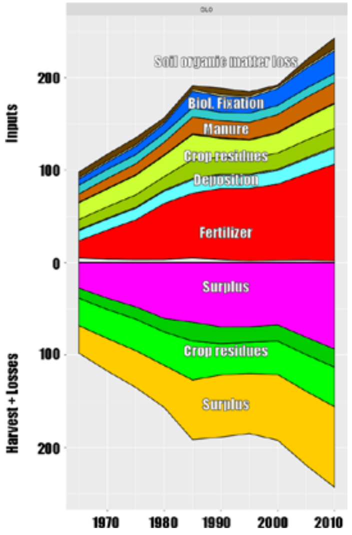

Fig2 (right): Global Nitrogen Budget for cropland soils (Tg Nr)

Our results can present balanced budgets for almost all countries, with soil nitrogen uptake efficiency ranging approximately between 40% in Asia and 70% in OECD countries. Estimating the depletion of soils was crucial in providing plausible efficiencies in many tropical countries. Our results can be used to find explanations for the development of nitrogen efficiencies and are fully consistent with future projections of the MAgPIE model (Bodirsky et al 2014).

Literature: Bodirsky et al. 2014. “Reactive Nitrogen Requirements to Feed the World in 2050 and Potential to Mitigate Nitrogen Pollution.” Nature Communications 5 (May).
Bodirsky et al. 2012. “N2O Emissions from the Global Agricultural Nitrogen Cycle – Current State and Future Scenarios.” Biogeosciences 9 (10): 4169–97.

Assessing and matching landuse with land suitability – the model development and landuse implications

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A sound understanding of the nutrients lost from farms and their transport and attenuation by catchment hydrogeology is essential for predicting their impacts on ecosystem health of receiving waters. Farm nutrient budgeting tools have been developed to account for, amongst other nutrient flows, leaching losses from farming systems. However, these models are limited to the simulation of nutrient flows mainly within the farm boundary and prediction of nutrients losses from the root zone. Catchment characteristics like land use, topography, rainfall, soil type, underlying geology, and subsurface geochemistry may further affect the transport and transformation of nutrients such as nitrate-nitrogen (NO_3-N) along flow pathways from farms to rivers and lakes.

We investigated and developed a simple model to account for the influence of different soil types and underlying geology on the transformation of soluble inorganic nitrogen (N) in the Rangitikei River catchment (3887 km^2), located in lower parts of North Island of New Zealand. The main soil types of the catchment were classified into low, moderate and high N attenuation capacities, depending on their texture, drainage rate and carbon content. The main rock types were categorised in a similar manner according to their hydraulic conductivity, organic matter and redox potential. Attenuation factors were spatially assigned to soils and rocks classes in the catchment in order to moderate predicted nitrogen loads to the river. The river N loads predicted in this manner were compared with the N loads measured in the river. We found that N loads measured in the river were significantly smaller than the estimates of the quantities of nitrogen leached from the root zone. The prediction of river N loads was significantly improved by incorporating the spatial effects of different soil types and underlying geologies on N attenuation in the subsurface environment of the Rangitikei River catchment.

We further applied the model to investigate the effects of changing landuse intensity, i.e. nitrogen leaching from farm systems, on water quality in the Rangitikei River. Three scenarios were considered; decreasing nitrogen leaching from low N-attenuation areas, increasing nitrogen leaching in high N-attenuation areas, and a combination of these two strategies. We found that a combination of targeted decrease of root zone N loss over low-low/low-medium (soil/rock) N-attenuation areas (~10,000 ha) and increase of N loss over high-high/medium-high N-attenuation areas (~80,000 ha) resulted into a significant increase of 55% in the root zone N losses, but a decrease of 6% in the river N loads. This suggests that cost-effective improvements in water quality can be achieved by selecting landuse practises and mitigation options according to the N attenuation capacity in the subsurface environment (below the root zone) in agricultural catchments. By taking a catchment perspective, we will be able to help redesign landuse practices in a coordinated fashion by spatially aligning intensive landuse practices with high N attenuation pathways, i.e. ‘matching landuse with land suitability’, in order to increase agricultural production while reducing environmental impacts.

Implications of the cover crop killing date on N and water cycles under different scenarios

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Background and aims

The cover crop (CC) killing date (KD) is a key management tool to enhance some of CC benefits such as soil water conservation and N recycling, and to minimize risks as the pre-emptive competition of CC with subsequent cash crops. Understanding the KD management in different scenarios and climatic conditions would be useful to achieve efficient management strategies.

Methods

The crop growth, water transport and nitrogen modules of WAVE model were calibrated by inverse calibration and validated with soil water content and soil inorganic N data from previous field experiments. Simulations were performed for current climatic conditions (with a 30-year database) and for climate change projections, combining different strategies: fallow vs. winter CC with different KD. Besides, other factors were combined: different initial soil water and N content in autumn; and two different planting dates of the subsequent cash crop. The cumulated biomass and CC transpiration, drainage, leaching, and N and water content in the upper soil layer previous to the cash crop planting were the variables evaluated.

Results

Table1. Effect of killing date (KD) and cash crop sowing date (HPD) on the decrease of N leaching and Nmin/soil water content (SWC) at 20-cm seed bed and at cash crop sowing date. The values represent the 10%/90% percentile decrease with average decrease in brackets. The reference is the scenario where no CC is used and early HPD.

KD	HPD	Leach (kg N ha-1)	Nmin (kg N ha-1)	SWC (%)
early	early	33/99 (57.3)	2/14 (8.9)	5.5/3.0 (5.0)
late	early	35/112 (63.0)	5/22 (15.0)	12.3/16.8 (14.0)
early	Late	31/91 (50.6)	0/11 (3)	3.3/3.0 (3.0)
late	Late	35/111 (61.7)	4/20 (13.2)	8.8/12.0 (10.0)

Conclusions

The KD delay caused a greater CC biomass that led to a higher resources extraction, which was considered an environmental advantage by reducing the risks of leaching and drainage, but at the same time it constituted a risk by creating a competition with the main crop, mainly in scenarios in which water and N were limiting soil resources. The cash crop planting date showed to be relevant, because it allowed reducing N and water competition. With climate change projections, the CC efficiency in leaching and drainage reduction was enhanced but at the same time the risk of soil depletion increased. Therefore, the CC kill date was confirmed as a key management tool and showed to have relevant implications with climate change scenario projection.

Acknowledgements

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Collection and Preservation of Urea Nitrogen from Grow-Finish Pig Urine

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Background and Aims

Animal manure contains organic matter and nutrients, specifically nitrogen, that are valuable to crop producers if it can be applied to nearby fields. These valuable components can become a significant source of environmental contamination if managed incorrectly. Concentrated animal production facilities are rarely close to sufficient cropland to fully utilize these resources and management becomes a disposal issue rather than a utilization opportunity. Urease inhibitors are typically added to soil with urea fertilizer. The goal of this work is to determine if urease inhibitors added to swine urine can effectively preserve urea nitrogen from pig production systems.

Methods

A 1 molar (6%) urea solution was used to represent swine urine. A laboratory grade urease enzyme from the Jack Bean plant was added to provide an activity of 1,600 units of activity per mole of urea, a level used in previous research to approximate the activity in soil. Inhibitors tested included N-(n-butyl) thiophosphoric tramide (NBPT) and Thymol (two commercial products applied with urea to soil), salicylhydroxamic acid (SHAM, a drug used to inhibit urease activity), sulfuric acid to adjust $\mathrm{pH} < 3.0$, and sodium hydroxide to adjust $\mathrm{pH} > 12.0$. Inhibitors and the enzyme solution were added to the urea or urine solutions, capped, and incubated at room temperature for six weeks. Samples were analyzed weekly. A subsequent test used NBPT and pH adjustment as the urease inhibitors with urine collected directly from sows.

Results

The increase in concentration of total ammoniacal nitrogen (TAN) was assumed to be due to urease activity. Commercial urease inhibitors lost between 6% (NBPT) and 17% (Thymol) of the original urea nitrogen as TAN in the first week but losses did not substantially increase during the remainder of the test period. Adjusting the pH of the urea solution above 12.0 and below 3.0 were effective at conserving urea, with losses less than 1% throughout the six-week holding period. The urine solution, tested with the NBPT, lost 5.5% of the urea during the first week and up to 10% during the entire holding period.

Adjusting the pH of swine urine above 12.0 and below 3.0 did not control urease activity after one week in comparison with the urea solution, losing 9% of the total nitrogen as ammonia, but the loss did not increase during the second week.

Conclusions

Inhibition of urease activity in swine urine is possible with the most promising method being pH adjustment. The difference in inhibition between pH of 3.0 and 12.0 is not clear from these studies and the impact of a commercial collection system on the urease breakdown of urea in urine is unknown. We will construct a pilot-scale system to test an in-house urine separation system with an integral recirculating inhibitor dosing system. Test will include low and high pH values and other inhibition methods.

Nutrient Recovery Membrane Technology: Pilot-Scale Evaluation

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Background and aims

Animal manure contains nutrients and organic matter that is valuable to crop producers if it can be applied to nearby fields, however this can be a significant source of environmental contamination if managed incorrectly. In most cases, concentrated animal production facilities are rarely close to sufficient cropland to fully utilize these resources and management becomes a disposal issue rather than a utilization opportunity. The goal of this work is to design and test a pilot-scale system to implement a hydrophobic, gas permeable, ePTFE membrane (U.S. patent held by USDA) to recovery ammonia from swine wastewater in a solution of sulfuric acid. The pilot-scale system was designed to replicate the laboratory results and to determine critical operational controls that will assist in design of farm-scale systems.

Methods

Through a series of preliminary experiments, we established operational criteria and selected a membrane with an ID of 0.40 cm, wall thickness of 0.06 cm, and a density of 0.45 g cm-3. The reactor consisted of 19 membrane tubes within a 5.1 cm diameter, 62.9 cm long reactor giving a membrane density of 1.5 cm2 cm3 of reactor. Wastewater first passed through a CO_2 stripping column (10.2 cm diameter, 139.7 cm length) where a small air stream (1.74 L min-1) stripped CO_2 from the wastewater and raised the pH one full unit, shifting the equilibrium to NH_3 and enhancing transport across the membrane. Batch tests (20 L) were run for 9-12 days with wastewater recirculating at a rate of 600 mL min-1. The recovery fluid inside the tubular membranes was a 0.01 N sulfuric acid solution with the pH automatically maintained below 4.0 standard units and recirculating at a rate of 6.0 mL min-1. Freshly collected settled wastewater and anaerobic digester effluent were tested to determine the mass of ammonia collected, the acid required to maintain the low pH of the recovery solution and potential ammonia losses to the atmosphere.

Results

The freshly collected wastewater had an initial mass of 35.6 g nitrogen but the NH_3 was only 14.5 g, leading to a recovery of 11.8 g (33% of initial) over 12 days. The anaerobic digester effluent had an initial mass of 33.2 g nitrogen with an NH_3 mass of 31.3 g. The higher fraction of ammonia helped push the recovery to 26.9 g or 81% of the initial nitrogen. Very little ammonia was lost with the exhaust air.

Conclusions

An optimized membrane reactor could be a viable tool in ammonia nitrogen recovery from a manure treatment system if used in conjunction with digestion. Higher economic value could be generated by further concentrating the ammonium sulfate product.

Novel legumes and technologies to reduce environmental N impact and increase production

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Background and aims

Pasture and forage legumes have been successfully used for decades in Australian agriculture to both enrich soils via biological N fixation and reduce the need for additional N fertiliser to grow high yield crops. This legume N is also organically bound and less prone than mineral fertiliser N to negative environmental impacts such as leaching into waterways and release into the atmosphere as the highly active greenhouse gas nitrous oxide.

Pristine has bred new varieties of these legumes that are much faster growing and higher yielding. That has increased their likely utility for a range of more environmentally friendly soil enrichment technologies. The aim of these studies is to define and quantify expected benefits of their use in agricultural systems in the EU and elsewhere around the globe.

Methods

Yield and other data from representative new varieties were obtained from various trials sown and grown in different seasons and climatic conditions in both China and Australia. These data were used to model likely utility within different agricultural rotations, their expected effects on soil nitrogen, and their capacities to reduce negative impacts from traditional agricultural production systems that are heavily reliant on mineral fertiliser N.

Results

Yield data show these new varieties grew much more rapidly than older types. Their top biomass can double in 5-6 days, and up to 5 000 kg/ha of top dry matter can be grown in as little as 60 days. Further, reflecting its outstanding feed quality, that biomass typically maintains protein levels of around 25% throughout the vegetative stage.

Modelling from this indicates significant advantages for these legumes. Because they require up to 40 kg of N per tonne of top growth, they will rapidly recover very large quantities of soil mineral N that could otherwise leach out of soils, and/or fix additional N where soil N is limited and insufficient for high productivity levels required of modern agriculture.

Conclusions

These data show that the new legumes will grow a viable forage or green manure in even short fallows between crops. In doing so, they will both reduce nutrient leaching and consequent water pollution and soil degradation, and add N where soil deficiencies exist. That will radically lower the need for fertiliser N to achieve high yields in future crops and minimise attendant negative impacts of that N on atmospheric and water pollution generally.

Additional work is now needed to further validate, demonstrate and quantify these various benefits in different climatic and edaphic zones, to determine individual variety fit within and between those zones and to cooperate with industry and government to facilitate adoption of these more productive and environmentally friendly agricultural systems.

Dynamisation of the nitrogen balance method with “CHN” crop model

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Background and aims

For several decades in France, nitrogen fertilizer rates have been calculated by using the nitrogen balance method and, in addition, a nitrogen management tool for the last application (*e.g.* Farmstar or NTester). However climate change affects agriculture in different ways, including through changes in average temperatures, rainfall and climate extremes, which are responsible for a more important variability in crop development, water irrigation requirement and nitrogen efficiency. Models are important tools to manage crops during the growing season, especially water and nitrogen amounts, knowing past climate and the probable future climate. A new tool is developing to manage nitrogen fertilization, using “CHN” crop model to estimate nitrogen requirement each day, according to soil nitrogen availability and crops nitrogen deficiencies.

Methods

“CHN” is a mechanistic crop model of the soil-plant-atmosphere continuum. It estimates daily flows of carbon (C), water (H) and nitrogen (N) between the different compartments of the system. The soil compartment is connected to a database, which regroups the different soils in French regions, and uses pedotransfer functions for estimating useful characteristics of soil. Stocks of water, carbon (stable and labile pools) and nitrogen (urea, ammonia, nitrate and organic pools) are daily modeled per 1 cm depth layers. The atmosphere compartment is connected to a database, with multiannual weather data throughout France. The plant compartment is based on the Monteith approach: leaf area is modeled and depends on simulated development stages. Leaf area intercepts radiation, which is converted into biomass. Roots growth is modeled and determines nitrogen and water stocks available for the plant. Growth is affected by nitrogen and water deficiency, using stress response functions.

This model is parameterized for breed wheat, durum wheat and maize and has been used to manage nitrogen under variable biotic stress conditions.

Results

Performances of biomass and nitrogen uptake estimations by “CHN” model have been calculated on winter wheat and maize databases. This model provides satisfactory predictions of biomass and nitrogen uptake, even under water and/or nitrogen stress.

During a growing season, it is possible to estimate crop development and growth with past climate, but also to plan development and growth in the future using probable future climate.

This crop model can be used to manage nitrogen amount to be applied, based on interpretation of nitrogen nutrition index (NNI), but also to nitrogen soil availability.

Conclusions

It is possible to manage nitrogen during crop growing season with the “CHN” model. This dynamic approach is more efficient that the common approach, with the nitrogen balance method plus a nitrogen management tool for the last application. Efficiency could be better with remote sensing data assimilation.

Nitrogen mineralisation and greenhouse gas emission from soil application of sludge from sludge treatment reed bed systems

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Background and aims

A sludge treatment reed bed system (STRB) is a good form of technology for dewatering and stabilising sewage sludge via assisted biological mineralisation. This creates a sludge residue of a quality that makes it suitable for use as fertiliser on agricultural land. The objective of this work was to evaluate the effect of treatment time (degree of stabilization) of sewage sludge residue in a vertical profile from three different STRBs on N mineralisation and GHG emissions after it is applied to soil.

Methods

Sludge residues cores (100 cm) were collected at three different STRBs in Denmark. Two cores from each site were cut into depth fractions (10 cm) and another core was mixed into bulk samples. Mixed and depth samples were characterized and incubated in a sandy loam soil for 160 days to estimate N mineralization and GHG emissions.

Results

Dry matter content increased from 20 to 27 % in the deeper (older) samples, whereas a reduction in TN and TC content was found for the deeper samples, which could be due to the mineralisation of the sludge residue along the profile and uptake of mineralised N by the reeds. Sludge samples from the upper (younger) part of the STRB profile resulted in high N mineralisation rates, i.e. the amounts of inorganic N accumulated at the end of incubation were 16%, 21% and 6% higher in the upper samples compared to deeper samples, suggesting that during the stabilization of the sludge, a significant part of N could be lost through volatilization, denitrification and leaching, or N uptake by reeds could be significant. Similar differences between upper and deeper samples were observed for CO2 and N2O emissions. The highest emissions were observed for the samples from the surface layers which could be related with the high content of labile organic matter and nutrients in the fresh sludge, serving as substrates for microbial decomposition processes and increase gas emissions from microbial respiration. The mixed samples for the three different STRBs systems resulted in very low N2O emissions and as low as the values of the sludge from deep part of the profiles.

Conclusions

This study supports that STRB is an appropriate technology to stabilize sewage sludge, increasing the dry matter content and decreasing the availability of labile compounds. Application of less stabilized residue sampled in the surface part of the reed bed results in higher soil N mineralisation, but also higher CO2 and N2O emissions. However, the combination of sludge from the entire reed bed appears to be a good solution to reduce soil N2O emissions, while still obtaining a high N availability in soil.

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N-Guru™: development of a novel technology to assist N-fertiliser decision making in grazed ryegrass-white clover pastoral systems

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New Zealand livestock grazing systems have traditionally been based around ryegrass-white clover based pastures, where biological nitrogen (N)-fixation by the legume component underpins overall pasture growth. However, N-fertiliser application in pastoral systems increased dramatically during the 1990's, with research showing it to be a profitable means of increasing pasture growth and feed supply. While this supported intensification of dairy land use, there were very few objective tools available to guide and educate farmers / farm consultants on strategic N-fertiliser management decisions. This was seen as a considerable limitation to efficient N-fertiliser management, given that pastoral research trials have historically shown wide variation in N-fertiliser responsiveness, both spatially and temporally. To fill this void, Ballance worked with AgResearch (a government-owned research institute) to develop N-Guru™, a decision support tool designed to assist farmers recognise and manage factors influencing pastoral N-fertiliser response efficiency.

The basis of N-Guru™ began with a PhD research project that developed a relationship between soil total-N and pasture N-responsiveness. This relationship was then developed further by undertaking a detailed pasture N-response trial, consisting of 20 trial sites of varying soil total N concentration (0.3-1.3% N) located within a large (340 ha) research farm. The resultant relationship based on the variables soil total N and fertiliser-N application rate was able to explain 72% of the variation in pasture yield response to N. This pasture N-response model was then validated using 41 trial sites across New Zealand, representing differing soil types, soil total N concentrations, and climatic influences on pasture growth.

N-Guru™ has since been commercialised, and represents the first pasture N-response tool that allows farmers to assess spatial and temporal variation in pasture N-responsiveness. The information N-Guru™ provides can help to improve N-fertiliser response efficiency, by reducing N-fertiliser inputs in areas (or at times) of poor pasture N response efficiency, and focusing N inputs into areas (or times) of greater pasture N response efficiency. This has potential to improve the economic return on N-fertiliser investment, while also reducing the direct environmental footprint of N-fertiliser use in grazed pastoral systems.

Modelling the Impact of N inhibitors and climate change on field N losses

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Introduction

Process-based models are available for assessing both the key drivers involved with variation in farm greenhouse gas (GHG) emissions and the impact of mitigation options. As abiotic drivers such as soil type and weather are major input parameters, the impact of future climate on any abatement options can be assessed.

Methods

We investigated the impact of feeding cows with DCD (mixed with supplementary feeds) on total field emissions. The impact of DCD was simulated by altering the rate of N nitrification in the model. Predictions of GHG emissions and carbon sequestration by process-based models (DNDC 9.4) were compared to the values obtained when adopting the more generic Tier 2 approach. Soil type (%clay, bulk density, etc.) data was obtained from the Teagasc Soil Information System and emissions were simulated for a range soil types including Cambisols, Luvisols, Gleysols and Podsols. Stocking rates were also varied from 1 to 2.5 LU ha-1. The impact of climate was simulated using HADGEM 2 and based on two representative concentration pathways RCP4.5 and RCP8.5 which represent an intermediate and the most intensive warming scenario, respectively.

Results

Urine N2O emissions using the process model outputs were significantly higher on heavy soils compared to using a Tier 2 emission factors but similar on free to medium drained soils. Conversely modelled nitrate leaching was higher on free-draining cambisols ($P<0.05$) using the process-based approach compared to the default emission factor. Feeding DCD reduced N2O emissions from 36% to 65% and nitrate leaching by 14% to 27% depending on soil type. Simulation of N2O emissions under RCP 8.5, resulted in a 40-80% increase in emissions over baseline climate and management, with a reduction in C sequestration on low % clay soils due to reduced summer primary productivity. Feeding DCD resulted in a 56% mean reduction of N2O emissions under this climate scenario.

Conclusions

This modelling study has demonstrated that feeding DCD to bovines can reduce reactive N emissions across soil types and at high stocking rates. In addition, this strategy could ameliorate future increases in reactive N losses resulting from climate-induced increases in weather volatility.

Acknowledgments

Funding was provided by the New Zealand Government to support the objectives of the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases (MPI/AgResearch Contract No. 15811). Any view or opinion expressed does not necessarily represent the view of the Global Research Alliance. DCD use in New Zealand is restricted to research. Protocols to ensure that DCD use in research does not enter the food chain are supported by soil and plant testing for DCD residues.

The new nitrification inhibitor DMPSA has the same efficiency as DMPP reducing N2O emissions from grasslands

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Background and aims

Nowadays intensive agricultural systems are based on large inputs of nitrogen fertilizers. However, this intensive management can lead to undesirable N2O emissions to the atmosphere. The use of nitrification inhibitors (NI) is one of the technologies able to reduce N2O emissions from agricultural soils. The objective of this work was to compare the efficiency of the new NI 3,4-dimethylpyrazole-succinic acid (DMPSA) with respect to 3,4-dimethylpyrazole-phosphate (DMPP) reducing N2O emissions from grasslands.

Methods

The work was conducted in ryegrass grassland in the Basque Country with a randomized complete block factorial design. Four treatments were applied: a control treatment without fertilizer, a second one with ammonium sulphate (AS) and two treatments consisting in the combination of AS with the new NI DMPSA and with DMPP, respectively. Three fertilizer applications were made which were followed by their respective cuts. The first one with 80 kg N ha-1 and the two following ones with 60 kg N ha-1 each. N2O emissions were measured using a close chamber technique and gas samples were analysed by gas chromatography.

Results

The application of both DMPSA and DMPP always reduced N2O emissions. The average reduction induced by NIs was around 50%. In all cases the emission factor remained below the 1% value proposed by IPCC, specially after the use of NIs.

Table 1. Cumulative N2O emissions (g N2O-N ha-1) after each fertilizer application, total N2O losses and emission factors (E.F.). Duncan Test (P < 0.05; n = 4).

	1st Fertilization	2nd Fertilization	3rd Fertilization	Total losses	E.F.
Control	163 c	48 c	85 c	296 c	-
AS	594 a	177 a	203 a	975 a	0.34
AS+DMPP	258 b (57%)	86 b (51%)	125 b (38%)	469 b (52%)	0.09
AS+DMPSA	302 b (49%)	122 b (31%)	112 b (45%)	536 b (45%)	0.12

Conclusions

The new NI DMPSA significantly reduces N2O emissions, being as efficient as DMPP.

Acknowledgements

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Validation of new nitrogen management tool on winter wheat based on remote sensing diagnostic and agronomic prognosis: “QN METHOD” - FARMSTAR® EXPERT

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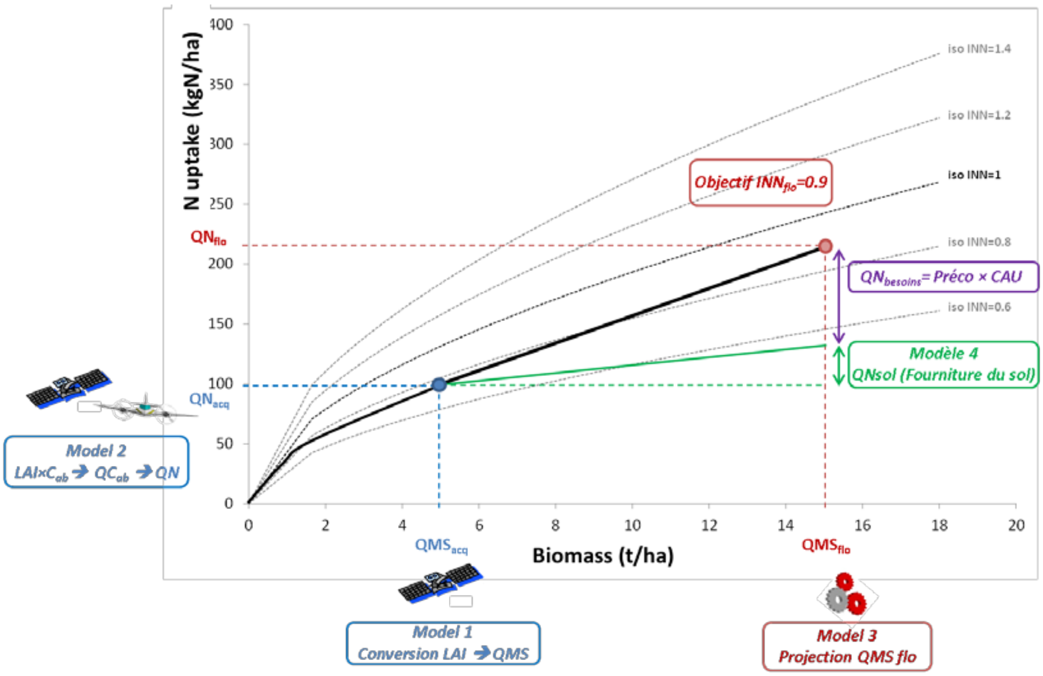
Background and aims

Since 2002 ARVALIS-Institut du Végétal the French institute of cereals, has operated the Farmstar® service to crop growers in France together with partners Airbus DS, a remote sensing specialist. 18 000 farmers subscribed to the service in 2016, it represented 800 000 ha of winter wheat, winter barley and rapeseed. The most important advice of this tool is the management of the last nitrogen application on wheat, which is new since 2015. This presentation will present the validation of this new model, named “QN method”.

Methods

Remote sensing is used to estimate Leaf Area Index (LAI) and Chlorophyll AB content (Cab), by using an inversion of radiative transfer model. LAI and LAI.Cab are respectively converted in biomass and nitrogen uptake. QN method” is a mechanistic model, which combines a diagnostic of nitrogen deficiency, according to the crop Nitrogen Nutrition Index (NNI), and an agronomic prognosis, using a growing forecast including water stress.



Each submodel of “QN method” has been validated with specific databases, and the method as a whole has been evaluated with field trials during 2 years.

Results and conclusions

Each submodel provides satisfactory predictions, but soil nitrogen contribution could be improved according a dynamic approach of nitrogen flows (*cf.* “CHN” abstract). The evaluation of “QN method” as a whole provides satisfactory results too. It permits to advice a nitrogen rate closed to the optimal rate, closer than an approach based on the nitrogen balance method alone, even under water stress or various biomass levels and it permits to produce +0.4% proteins.

Producing more rice with less fertilizers: Determining optimum nitrogen rate and placement method for lowland rice cultivation

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Background and aims

Nitrogen fertilization is critical for cereal production. However, more than 50% of applied nitrogen is not utilized by crops and lost to the environment as reactive forms (ammonia, nitrate, nitrogen oxides) posing both economic and environmental concerns. Therefore, fertilizer management should consider the 4R concept – right methods, right time, right rates, and right sources to increase use efficiency, crop yield, soil health, and farm profits and to reduce negative environmental effects.

Methods

Field studies were conducted across different locations in Bangladesh using different N rates and methods of application (deep placement vs. broadcast). Grain yields, nitrogen use efficiency (NUE) and nitrogen loss as ammonia volatilization, nitrous oxide (N2O) and nitric oxide (NO) emissions were measured continuously throughout rice-growing and fallow seasons using an automated gas sampling and analysis system under two irrigation regimes—alternate wetting and drying (AWD) and continuous flooding (CF).

Results

Results of multi-location experiments confirmed the multiple benefits of urea deep placement (UDP), including reduced nitrogen losses through ammonia volatilization and greenhouse gas N2O and NO emissions. Across the years and sites, UDP increased yield on average by 21% as compared to broadcast urea while using at least 25% less fertilizer. The magnitude of increase was larger under AWD, because AWD significantly reduced grain yields (8%) compared to CF at broadcast urea. However, yields UDP were similar between AWD and CF. UDP reduced N2O emissions by up to 80% as compared to broadcast urea under CF irrigation. The effects of UDP on N2O emissions under AWD irrigation practices were site specific: depending on the duration and intensity of soil drying, emissions were reduced under mild soil drying but increased with more intense soil drying. With the reduction of losses and increased plant uptake, UDP increases N use efficiency up to 80% compared to 30-45% of broadcast application.

Conclusions

These results along with other studies conducted across different locations in Bangladesh suggest that UDP could be one the best management techniques to achieve the multiple benefits of increasing grain yields, farm profits, and nitrogen use efficiency while reducing negative environmental effects. However, wider adoption of UDP requires government and private sector initiatives to make fertilizer briquettes more widely available through industrial-level briquette production while developing suitable tools for smallholder production systems to reduce the labor intensity of manually placing UDP briquettes.

Effect of a nitrification inhibitor on nitrous oxide emissions and ammonia volatilization from a maize group

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Background and aims

Application of organic or mineral N fertilizers in the field triggers losses of ammonia (NH3) to the atmosphere. These losses are of concern not only from the economic point of view, but also because they may cause threats to the environment and human health. The principal objectives of this study were to assess the inhibitory effect of 3,4 dimethylpyrazole phosphate (DMPP) (Zerulla et al., 2001; Weiske 2001) on N2O emissions and NH3 volatilization in an irrigated maize crop (Zea Mays), under Mediterranean conditions, fertilized with pig slurry (PS) and Calcium ammonium nitrate (CAN) in split application, adjusted to provide 200 kg N ha-1 .

Methods

First fertilization was applied ten days before sowing (on 20th April 2015) and the second one at top-dressing (on 23rd June 2015). The crop was irrigated following common agricultural practices in the region, twice per week. The first fertilization consisted in the application of organic fertilizer, Pig Slurry with (PS plots) and without Nitirfication Inhibitor (NI), PSNI plots. In the second fertilization (23rd June 2015), CAN was applied to the soil surface at a rate of 150 kg ha-1 with and without the DMPP (provided by EuroChemAgro ®) in the PS and PSNI treated plots, respectively. Four plots (40 m × 40 m) were selected and arranged according to the two treatments with two replicates per treatment. All plots were surrounded by unfertilized areas according to IHF principles (Denmead, 2008)

Ammonia concentrations were measured during 20 days after each fertilization event. The IHF (Integrated Horizontal Flux) method was used as a reference technique to estimate NH3 volatilization using Passive Flux Samplers (PFS) (Sanz-Cobena et al., 2010). Afterwards, commercial software (WindTrax 2.0 ThunderBeach Scientific, Canada) was used to estimate NH3 emission by applying the bLS model (Flesch et al., 2007).

Results

At the end of first round of measurements the average of NH3 cumulative emissions in PS plots was 7.11 kg N ha-1. Approximately 14% of N applied to the soil was volatilized as ammonia. The NH3 mean cumulative emissions in the treatment with NI (PSNI) were 1.01 kg-N ha-1. Thus, only 2% of N applied was lost due to ammonia volatilization. Despite that losses in pig slurry treatment were 85% greater than in the treatment with DMPP, there was not significant difference between treatments (P>0.10)

The NH3 cumulative results obtained at the end of the second round of measurements showed that the amount of volatilized NH3 for CAN and CAN + DMPP was 3.25 and 1.28 kg N ha-1 respectively. Emissions associated with CAN without NI were 60% greater than those of treatment with NI, but without significant difference between treatments. Thus, at the end of the second round of measurements, NH3 losses from PS reached 2.1% of the TAN applied, while losses from PS+DMPP amounted to 0.85%.

Linear regression was performed among the NH3 cumulative emissions values determined with IHF and BLS technique. A significant correlation was obtained among these values with a correlation coefficient of 0.82.

In terms of N2O emissions, the application of DMPP with PS (PSNI) in the first fertilization had a non-significant difference with C treatment. As a result of the second fertilization, N2O emissions were surprisingly higher in plots where the NI had been applied. This was thought to be associated to favoured denitrifying conditions due to intense irrigation. In any case, differences between cumulative fluxes from PS and PSNI at the end of the measurement period were not significantly different.

Conclusions

In conclusion there were not significant difference between treatments in N2O and NH3 emissions, but, unexpectedly, DMPP have not been highly effective in terms of N2O mitigation but have reduced ammonia volatilization in both fertilizations, mostly when organic fertilizer was applied.

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Soil use change, a consequence and a driver to alteration of soil quality

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Background and aims

Soil use is generally related to soil organic matter depletion and water contamination with nitrates, as well as to other factors that may alter water and soil quality. Changes in soil use are a result of external drivers mainly related to agricultural policies and food requirement increase determining agricultural intensification.

Methods

Data about historical soil uses in Portugal was collected in official databases, and drivers for soil use change were identified. Data was used to correlate drivers to change with soil use evolution and water quality impact in Portugal mainland.

Results

European rules have determined soil use changes over the years according to the European commodities demand, as well as to soil characteristics and agriculture common policy. Many areas have been converted from agricultural use to forest use and due to the industrialization of agriculture, intensification of crops such as maize, rice and tomato have taken place. Urban areas have increased in number and in area and this resulted in the creation of artificial areas with corresponding soil and water degradation. These are mainly due to real estate speculation and road network expansion. Permanent crops such as vineyards and olive orchards were first abandoned and recently their installation as been encouraged as a tool for sustainable soil use. All soil use changes have resulted in soil organic matter and water quality depletion, with associated nitrate losses and expansion of number and area of nitrate vulnerable zones, as well as the increase of hectares with desertified soil.

Conclusion

Soil use has changed mainly according to EU Directives rules and has resulted in both agricultural intensification and forest areas expansion. This has resulted in soil quality depletion and water quality decline, namely by nitrate pollution and desertification areas increase.

Acknowledgement

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Limus®: a novel combination of urease inhibitors reducing ammonia emissions from urea containing fertilizers and its performance concerning environmental and agronomic parameters, handling, transport and storage properties

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Urea containing fertilizers are the most important mineral nitrogen (N) source globally. The consumption of N in the EU28 in 2014 from urea and urea-ammonium-nitrate solutions (UAN) was 2.391 kt N and 1.364 kt N respectively. The main disadvantage of urea-containing fertilizers is N volatilization losses in form of ammonia (NH3). Depending on weather and on soil conditions the extent of such losses can be up to 80% of the total applied N. The European Environmental Agency defined the ammonia-nitrogen (NH3-N) losses between 13% to 17% and between 8% to 10% of the total applied N for urea and UAN respectively.

BASF has developed the N stabilizer Limus® to reduce NH3 losses from urea containing fertilizer. Limus® is a novel combination of the urease inhibitors N-(n-butyl)-thiophosphoric-triamide (NBPT) and N-(n-propyl)-thiophosphoric-triamide (NPPT) within an innovative polymer based formulation. Several studies were carried out under laboratory, greenhouse and field conditions to evaluate the effects of Limus® on NH3 emissions, agronomic parameters, handling, transport and storage properties.

Field experiments carried out in several European countries (2010-16) showed the efficacy of Limus® as urease inhibitor reducing NH3 emissions up to 89% from urea and 74% from UAN. Results on marketable yield indicated an increase of 4% and 5% compared to untreated controls for winter wheat and maize respectively. Laboratory and docking experiments demonstrated that the combination of two active ingredients (AI) led to higher efficiency and reliability under different soil conditions compared to the use of the single active ingredient NBPT. The optimized formulation of Limus® resulted in several advantages in comparison to market standard products. Significant differences were observed for the AI stability on treated granular urea during storage. Limus® dried faster on urea. Abrasion of the AI from the surface of urea granules after mechanical stress was lower for Limus®. The formulation stability of Limus® was better at 54°C for 14 days as well as at -10°C for 14 days. The maximum potential of Limus® reducing NH3 emissions was evaluated for the EU28 in 2014. The results showed an emissions reduction potential of 347 kt NH3 for urea and 67 kt NH3 for UAN.

Vizura®: the nitrification inhibitor to enhance the fertilizer value of slurry and biogas digestate. Review of European studies showing the impact of using Vizura® on environmental and agronomic parameters

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Slurry from livestock and biogas digestate are valuable fertilizers used in large amounts all over Europe. However significant amounts of nitrogen are lost during and after fertilization with a negative impact on the environment. Depending on environmental and soil conditions, the ammonium (NH4+) applied with the slurry or biogas digestate is rapidly converted into nitrate (NO3-). During this process called nitrification, nitrogen losses can occur in the form of nitrous oxide (N2O) which has 298 times higher greenhouse gas potential than carbon dioxide (CO2). In addition, nitrate is easily mobile in the soil compared to ammonium and therefore can move to lower soil layers and finally into the groundwater.

BASF has developed the nitrogen stabilizer Vizura® to reduce nitrogen losses and to enhance the value of slurry and biogas digestate. The addition of Vizura® (1 – 3 l/ha) to slurry or biogas digestate, slows down the conversion rate of NH4+ into NO3- significantly. The active ingredient 3,4-dimethylpyrazole phosphate (DMPP) keeps the level of NH4+ stable for a longer time by inhibiting the action of the Nitrosomonas bacteria for a certain period. Several studies were carried out under laboratory, greenhouse and field conditions to evaluate the effects of applying Vizura® to slurry or biogas digestate.

Results showed the efficacy of Vizura® as nitrification inhibitor reducing the amount of N2O emissions by 50%. Vizura® also reduced the risk of NO3- leaching especially after high rainfall events in light sandy soils. Field trials carried out in several European countries showed a higher nitrogen uptake by winter wheat and maize plants when slurry or biogas digestate were treated with Vizura®. Positive side effects of nitrification inhibitor application may comprise a better mobilization of phosphorus and micronutrients due to the rhizosphere acidification. Higher uptake of phosphorous was measured on maize plants fertilized with slurry treated with Vizura®. Field experiments carried out in different European countries showed an average increase of marketable yields by 5% on winter wheat and 7% on silage maize compared to untreated controls. The maximum potential of Vizura® reducing N2O emissions and NO3- leaching was estimated for the EU28 in 2013. The results showed an emissions reduction potential per year of 72.5 kt N2O (21.7 million metric tons of CO2 equivalent) and a reduction of 2.9 million metric tons of NO3- respectively.

Effect of nitrogen supply on biomass quality for biorefining

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Background and aims

Agricultural residues in the form of straw are potential feedstocks for biorefinery purposes. Globally, wheat is among one of the most important cereals and it is estimated that around 800 Tg of straw residues are produced annually from wheat[1]. Given the interest and expected future demand for residues in cellulosic biorefineries, it is required to increase not only the production of grain but also the straw output per hectare. It is therefore a target in plant breeding to obtain wheat cultivars with increased straw yields without compromising the grain yield – in other words maximize total biomass output. Nitrogen supply is important for grain yield and quality, but limited knowledge is available regarding the effect of nitrogen application on straw yield and straw quality. In a biorefining perspective, desirable quality traits are high content of carbohydrates, in particular cellulose, in combination with a plant cell wall that is easily degradable in a bio-conversion process.

Methods

Field experiments embracing 14 modern genotypes of winter wheat and one triticale genotype (cv. Trilobit) were conducted during three seasons (2013-2015) in Taastrup (Denmark). Three levels of N fertilizer (100, 160 or 220 kg N ha^{-1}), were applied. The straw was analysed for the content of nitrogen and carbon, cellulose and lignin. The quantity of glucose and xylose released during enzymatic saccharification was analysed following pretreatment at 190°C for 10 min at pH 4.8, succeeded by hydrolysis using of the commercial enzyme preparation Cellic CTec 2 (Novozymes, Denmark)[2,3].

Results and discussion

The field experiments revealed a clear potential for improving the total biomass output by increasing the straw yield without compromising the grain yield. In particular triticale showed potential for very high yields, reaching 20-25 t of total dry matter per ha. Nitrogen application had a clear positive effect on total biomass output. Nitrogen application also modified the composition of the cell walls but, importantly, neither the concentration of cellulose nor the enzymatic saccharification efficiency were affected. There was a negative correlation between N application and silicon concentration which might be advantageous for some biorefinery applications, e.g. thermochemical processes or lignin valorization.

Conclusion and outlook

There is a genotypic potential for increasing wheat straw yield without compromising grain yields. External nitrogen input affects the quantity of cellulose and lignin harvested as well as the cell wall composition, but the quantity of glucose and xylose released per unit straw dry matter during enzymatic saccharification of wheat straw does not differ among modern genotypes and are not affected by straw nitrogen status. This simplifies biorefining of wheat straw because it reduces the need for analysis of the straw prior to processing it.

Acknowledgements

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Balancing optimum fertilisation and N losses in dairy systems

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Background/Aims

Determination of optimum nitrogen (N) fertilisation rates which maximise pasture growth and minimise N losses is challenging due to variability in plant requirements and likely near-future supply of N by the soil. Remote sensing can be used for mapping N nutrition status of plants and to rapidly assess the spatial variability within a field. An algorithm is, however, lacking which relates the N status of the plants to the expected yield response to additions of N.

The aim of this simulation study were to develop multi-variate model for determining N fertilisation rate for a target percentage of the maximum achievable yield based on the pasture N concentration (ii) use of the multi-variate model for guiding fertilisation rates, and (iii) evaluation of the model regarding pasture yield and N losses, including N leaching, denitrification and volatilisation.

Methods

A simulation study was carried out using the Agricultural Production Systems Simulator (APSIM). The simulations were done for an irrigated ryegrass pasture in the Canterbury region of New Zealand. A multi-variate model was developed and used to determine monthly required N fertilisation rates based on pasture N content prior to fertilisation and targets of 50, 75, 90 and 100% of the potential monthly yield. These monthly optimised fertilisation rules were evaluated by running APSIM for a ten-year period to provide yield and N loss estimates from both non urine and urine affected areas. A comparison with typical fertilisation rates of 150 and 400 kg N/ha/year was also done.

Results

Assessment of pasture yield and leaching from fertiliser and urine patches indicated a large reduction in N losses when N fertilisation rates were controlled by the multi-variate model. However, the reduction in leaching losses was much smaller when taking into account the effects of urine patches.

Conclusions

The proposed approach based on biophysical modelling to develop a multi-variate model for determining optimum N fertilisation rates dependent on pasture N content is very promising. Further analysis, under different environmental conditions and validation is required before the approach can be used to help adjust fertiliser management practices to temporal and spatial N demand based on the nitrogen status of the pasture.

Acknowledgements

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The role of seed coatings in enhancing rhizobium colonisation and yield increases in pulse crops in the northern Mallee of South Australia

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Abstract

The colonisation of pulse crops by rhizobia in the northern mallee of South Australia is at times highly variable and in many cases inadequate for optimum plant growth. The aim of this work was to collate recent research publications to develop a seed coating that would enhance colonisation of seed coated rhizobium onto roots in low rainfall cropping regions such as the northern Mallee of South Australia. The coating of chickpeas, peas and lentils in this trial based out of Loxton with a product based on kelp, zinc, manganese, molybdenum and bacterial suspensions (Foundation TN) at 5L per ton of seed had significant benefits in plant growth and development. There was also a visual reduction in the incidence of root disease in treated plants. Statistically significant yield results were seen with Lentils (614kg/ha control to 677kg/ha coated), Field peas (729kg/ha control to 911kg/ha coated). Increases in Chickpeas were not significant (602 to 640kg/ha) but this may have been as a result of the lower seeding rate and severe frosts at flowering. Plants that had coated seeds in conjunction with rhizobia had greater numbers of efficient colonies and reduced root pathogens suggesting that good colonisation by rhizobium suppresses pathogenic infection points. Post-harvest deep N soil testing revealed an increase from 43kg N/ha to 61kg N/ha in composite soil samples from the lentil trial site indicating an increase in 18kg N/ha where rhizobium colonisation was enhanced. Trial results over recent years have suggested that appropriate seed coats that enhance root colonisation by rhizobium are highly cost effective and in maximising the symbiotic relationship between rhizobium and the host species.

Evaluation of the effectiveness of the use of organic fertilizer for the crop production

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Background and aims

According to the Ministry of Ecology and Natural Resources, almost all surface water and groundwater are contaminated with pollutants in Ukraine. According to UNESCO intensive eutrophication of inland water bodies leads to the deterioration of the water quality of Black and Azov Seas. In terms of water resources management and water quality, Ukraine took 95th place among 122 countries of the world. This is indicative of an excess supply of nutrients to water bodies. On the other hand, there is used an insufficient number of organic and mineral fertilizers in agriculture.

The aim of our study was to evaluate the effectiveness of the use of manure, produced in animal husbandry, for crop production, in Ukraine.

Methods

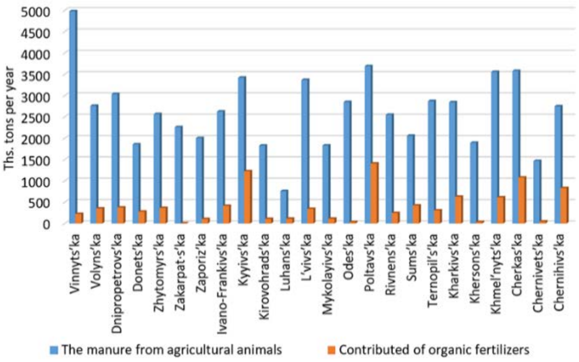
To calculate the amount of manure we used data from official statistics of Ukraine on the number of animals. The amount of manure is calculated according to the document: System of removal, processing, preparation and uses of manure, VNTP-APK09.06, 2006. To calculate the potential reserves of nitrogen used coefficients (Table 1).

Table 1.

The manure of farm animals	The content of active nitrogen, %	References
Cattle	1,4	Canh et al., 1998; Whitehead, 2000
Pig	0,9	
Poultry	1,5	

Results

Quantities of manure excretion of the agriculture animals were calculated for the regions of Ukraine. The total amount of manure excretion was 63,353.0 thousand tons. This amount of manure contains 816.4 thousand tons of reactive nitrogen. Only 9,636.3 thousand tons of manure, which contain 139.7 thousand tons of nitrogen, is used for fertilizing the soil (Fig.1). Only 17, 1% of the nitrogen of manure is used to fertilize soils (Fig.2). As shown in our previous studies, insufficient use of nutrients for crop production leads to the degradation of soil organic matter, which in the future could become irreversible.



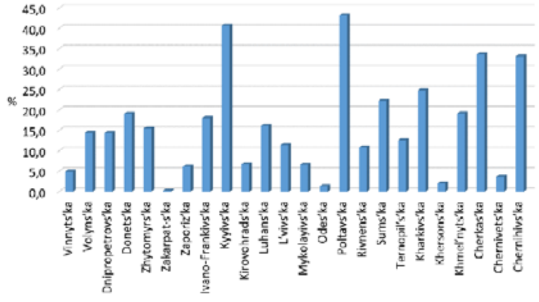


Fig. 2. Using of nitrogen of manure as organic fertilizer, %

Conclusions

Agroecosystems require an application of nutrients for a balanced food production. Violation of balance of nitrogen cycle may lead to irreversible destruction of them.

Effects of land use changes on the provision of ecosystem services in relation to implementation of nitrogen reduction measures – a scenario study

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Background and aims

When nitrogen (N) measures are implemented the main focus is on the nitrate leaching reductions and the direct costs. However, the measures that include changes in land use will also have an effect on the provision of a range of ecosystem services. This stresses the need to include additional factors in evaluations of the cost and benefits of implementing N measures. This study addresses the effects of changes in agricultural land use on the provision of ecosystem services in three study areas in Denmark. The aim of the study is to evaluate the effects on the provision of ecosystem services are evaluated based on both stakeholder-guided and expert-guided land use scenarios.

Methods

The scenarios cover the catchments areas of the water courses Hagens Møllebæk, Binderup Å, and Gjøl canal. The land use scenarios are formulated with special focus on change from arable land to more extensive land uses. Based on the scenarios the impact on ecosystem services of land use changes is estimated. The scenarios are developed in a GIS based landscape model where N leaching is estimated with the Nles4 model. The effects on ecosystem services are estimated in the MAES model.

Results

The results show that land use characteristics have an effect on the provision of ecosystem services. The estimated provision of ecosystem services in the current (baseline) land use is compared with the provision in relation to three scenarios with focus on implementing land based measures to reduce N leaching. The evaluated scenarios focus on wetlands, drinking water protection (afforestation), and extensive grassland.

Conclusions

The results indicate that the cost of implementing measures to reduce N leaching is partly compensated by the benefits of increased provision of the ecosystem services in focus. Consequently, the external effects of implementing N specific measures should be taken into account in impact assessments. In relation to collaborative planning processes it is important to include as many ecosystem services as possible to engage with the objectives of the different stakeholder.

Acknowledgements

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Collaborative planning in natural resource management – the case of regulation of nitrogen in the agri-environment

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Background and aim

Environmental issues have been regulated through statutory planning since the 1970s in most OECD countries. After decades with focus on centralized, top-down oriented approaches in environmental planning and regulation, collaborative and participatory bottom-up oriented planning approaches are gaining momentum. The aim of this paper is to test a collaborative planning approach in the regulation of nitrogen in the farming sector. The overarching question is whether this regulation can be organised locally rather than by general, national rules. The benefits by adopting a local approach is that local knowledge on, e.g. farming practices, soil, water and climate, can feed into the regulation process, making general rules less important, maybe even obsolete.

Methods

The planning approach adapted for the study was inspired by concepts of collaborative planning in urban areas and various other concepts of participatory environmental planning. The approach was tested simultaneously in six case areas of rural Denmark, each comprising small watersheds (20-76km^2). The strategic aim was to reduce the loss of nitrogen from farms to the aquatic environment. The planning process consisted of two stakeholder workshops bracketing a scenario formulation process. As decision support a fine-scaled nitrogen leaching model applied in an interactive GIS platform was developed. Stakeholders comprised farmers, civil servants from municipalities, NGOs, farm extension services, private enterprises and interested citizens. At the first workshop stakeholders gave inputs to scenarios in which land use and land cover changes were simulated, and the resulting loss of nitrogen was estimated. At the second workshop the scenarios were presented and discussed. Success criteria for this planning procedure comprised: stakeholders became engaged in a dialogue, provided inputs to the scenarios, and accepted the premises; they followed presentations in the second workshop and commented on the outcomes.

Results

The six case processes gave different outcomes in terms of success of formulating solutions. They differed in the degree of collective understanding of the aim, in the level of conflicts internally among stakeholders, and in the degree of cooperation and the sense of accomplishment of win-win situations. Each case area had a unique situation, but in general the more successful case areas had a strong existing network, accomplished a common understanding of the target, could keep conflicts at a low level, and managed to work collaborative towards win-win situations.

Conclusion

The success of the collaborative planning process in our case areas depends on, e.g, existing networks and sense of place-attachment. In the best cases there is a basis for initiating concrete projects, in the worse cases the process suffer from conflicts at several levels. Conclusively, given the right conditions of communication and collaboration, hard environmental problems can be solved by bottom up approaches.

Acknowledgements

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A landscape ecological perspective on the regulation of N, P and organic matter in the Danish agri-environment

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The spatial configuration of the agricultural landscape and the organization of farming practices have strong effects on the flows and balances of nutrients and organic matter and their environmental impacts. This has been acknowledged to varying degree in the different generations of action plans, legislation and strategies implemented in Denmark to reduce the impact on the terrestrial and aquatic environment. The aim of this paper is to analyse three decades of environmental regulation of the farming sector in Denmark, with a focus on the underlying landscape paradigms and agro- and landscape ecological models.

The study includes analyses of policy documents, action plans, legislation, guidelines and other implementation papers. We identify spatially targeted measures and underlying assumptions regarding the landscape and assess the landscape component of models used for policy design and evaluations. Additionally, we interview key stakeholders involved in the different stages of implementation to identify the main drivers and motives in policy design.

There has been a considerable development of ecological models and availability of data during the three decades of N, P and OM related regulation in Denmark. In the early plans of the 1980s focus was on simple measures such as improving manure storage facilities and handling with no or few links to landscapes. This changed with the introduction of fertilization plans (1987) and norm based fertilizer rules (1991). However, the measures were still largely based on simple field-scale models focusing on leaching from the root-zone ignoring spatial variation and horizontal fluxes. Gradually more advanced models that included the landscape level were introduced along with the implementation of measures with spatial components such as wetland restoration, environmental approval of husbandry farms, buffer-zones and voluntary schemes targeted to designated areas. Today tools include the spatial configuration and organization of the landscape in the modelling and assessment of nutrient fluxes and balances. However, the use of modelling tools is increasingly questioned as to their reliability arguing that on-site specific measurements rather than model results are needed.

The models and data required to design and assess spatially differentiated measures to reduce the nutrients load from Danish agriculture has been developed and improved considerably since the implementation of the first mitigation measures in the mid-1980s. Also, the need for spatially differentiated policies was identified at an early stage of the process we have described. However, the implementation of spatially differentiated measures has been slow as a consequence of the Danish approach to (non)targeting. Today there is a broad consensus among stakeholders and farmers on the need for spatially differentiation and the next generation of measures are likely to reflect this. This will target the mitigation efforts towards high load areas affecting vulnerable ecosystems, whereas it is still uncertain if it also will include fewer restrictions on farming in areas which have less environmental impact.

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Estimating nitrate leaching from forests in fragmented agricultural landscapes with and empirical model

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Background and aims

Nitrate leaching from forests have been considered insignificant in agricultural dominated landscapes in Denmark and therefore largely ignored in freshwater protection planning. However, this assumption was challenged by observation of high nitrate leaching at many sites and particularly at the edges of forests and forests close to livestock farms where the nitrogen deposition is high. In intensively used agricultural landscapes forests are often fragmented and edges (0-50m) may make up 50% of the actual forest area in a groundwater catchment. In Denmark, 35% of the total forest area is edges (0-50m) that may receive up to 50% higher N deposition than in the interior forest. Similar circumstances are found in other lowland areas of Europe (e.g. Belgium, the Netherlands and parts of Germany).

Methods

A simple empirical model that estimates nitrate leaching from forest patches in complex agricultural landscapes were developed. Regional estimates for NO_x and NH_y deposition were compared to throughfall measurements from >50 sites to derive constants that could scale the regional estimates to different forest types and to throughfall measurements from edges. Simple response functions for the biomass and soil sinks were developed from intensive N cycling studies in a few forest sites. Finally N leaching loss was estimated from a mass balance equation. The scaling factors and equations were implemented in a GIS system. The model performance was evaluated using published N leaching/nitrate concentration data from Danish forest and forest edges. An agricultural landscape (2 x 2 km) on sandy soil with two livestock farms and small as well as larger forest patches were chosen for model validation. Twenty-five soil samples (composite of five from c. 400 m^2 plots obtained with an auger from 75-100 cm depth) representing different forest polygons and categories in the GIS model were collected and extracted to determine nitrate concentrations.

Results

The model could reasonably well predict the input-output relationship of N observed in forests throughout Denmark. Observations of elevated nitrate concentrations from studies in different forest edges on fine and medium textured soils could be predicted by the model ($r^2=0.61$; $P<0.01$), but for coarse textured soils nitrate concentrations were overestimated. The model performance on the validation landscape was relatively poor and it appeared again it was due to overestimation of nitrate concentrations in forests on sandy soils. Thus the model needed some adjustment and particular the soil N-sink in sandy soils had to be increased.

Conclusions

Compared to the relative few parameters needed for the model, the performance (after adjustment of the parameters for sandy soils) was good and sufficient for the purpose of N pollution risk assessment for complex groundwater catchments.

Preliminary results of nitrogen leaching under minimum and no-tillage in northern Italy

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Background and aims

Conservation agriculture practices are recognized to bring environmental benefits. However, there are conflicting results in the literature about the effect of noninversion tillage on nitrate (NO_3-N) leaching [1, 2]. The hypothesis of the present work was that the expected differences in soil structure between conventional, minimum and no-tillage soils lead to differences in NO_3-N leaching. A field trial where minimum and no-tillage were implemented in 2011 was monitored in order to evaluate the effect of different agricultural soil management on NO_3-N leaching from October 2015 to August 2016 in northern Italy. This experiment was set up within the European Life-HelpSoil project (LIFE12 ENV / IT / 000.578).

Methods

The field experiment was set up in Gazzo, Po Valley (45°11′N 10°54′E; 23 msl), northern Italy. Winter wheat (*Triticum aestivum* L.) was cropped in 40 m wide X 500 m long field plots from October 2015 to early July 2016 under three soil managements with two replicates: minimum tillage (MT), sod seeding (NT), and conventional tillage (CT). The fertilization amount was 180 kg N ha^{-1}. For each tillage treatment, NO_3-N leaching was estimated using the formula proposed by [3] on the basis of (i) the NO_3-N concentration measured in the soil solution samples collected with porous suction cups at 70 cm depth and (ii) the water amount draining through the same soil layer. The latter value was estimated by the SWAP simulation model [4], which was first calibrated using the soil water content data collected during the monitored period at 20, 40, 70 cm depth. Data of NO_3-N concentration in soil solution and leaching were analysed using a linear mixed model (IBM SPSS 24.0). Crop-related data were: number of plants emerged, leaf area index (LAI), aboveground biomass and yield at the harvesting. Such data were analysed with a one-way ANOVA.

Results

The concentration of NO_3-N measured at 70 cm depth was below the Nitrates Directive limit of 50 mg $^{-1}$ over the entire monitoring period. From February to August, leaching in CT (16±2 kg NO_3-N ha^{-1}) did not differ significantly from NT (15±3 kg NO_3-N ha^{-1}), whereas it was lower in MT (8±4 kg NO_3-N ha^{-1}, $p<0.01$). Although the number of emerged plants and LAI values were higher in CT than in MT and NT, grain yield was significantly higher in NT (7 Mg DM ha^{-1}) and MT (7.4 Mg DM ha^{-1}) than in CT (5.8 Mg DM ha^{-1}).

Conclusion

The data shown in the present work are intended to be the preliminary results of a long term monitoring of the NO_3-N leaching occurring under conservation tillage in comparison with the conventional one. Noninversion tillage appear to be promising to ensure profitable yields and to reduce NO_3-N leaching.

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Modelling spatial nitrogen attenuation and land-based nitrogen loads to rivers

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Intensive agricultural activities are generally associated with runoff and/or leaching of nutrients (N & P) from agricultural soils and their elevated levels in receiving freshwater bodies. Farm nutrient budgeting tools have been developed to account for, amongst other nutrient flows, leaching losses from farming systems. However, these models are limited to account for nutrient flows into and within the farm boundary and the prediction of nutrient losses from the root zone.. However, catchment characteristics such as soil types, underlying geology, and subsurface geochemistry may further affect the transport and transformation of nitrogen as it travels from farms to rivers and lakes. The chemical reduction of nitrate-nitrogen is one well known attenuation process in subsurface environment. Therefore, leached nitrogen from agricultural soils may or may not contribute to the nitrogen loading of surface waters.

We analysed the influence of different catchment characterises, especially soils and underlying geology, on the spatial variation of nitrogen attenuation and loads to streams and rivers in two large agricultural catchments. Our study areas, the catchments for the Manawatu and Rangitikei rivers are located in the Manawatu-Wanganui region in the lower North Island of New Zealand. We defined and quantified a nitrogen attenuation factor (AF_N) by comparing the modelled losses of nitrogen from the farms' root zone with measured soluble inorganic nitrogen loadings in the rivers. Catchment characteristics were extracted using ArcGIS® and their relationships with AF_N were evaluated using regression analysis.

We found significant variation in AF_N values, ranging from 0.18 to 0.94, among different sub-catchments. The AF_N showed a positive relationship with fine textured soils (e.g. clay loam), compared with a negative relationship with well-drained soils and base flow index (*BFI*). The main soil and rock types of the study catchments were classified into low, moderate and high nitrogen attenuation capacity classes and assigned corresponding AF_N values. This classification was then employed to predict land-based soluble inorganic nitrogen loads to the rivers. The predicted river soluble inorganic nitrogen loads showed a strong match with the measured river loads. We plan to apply this simple hydrogeologic based model to other catchments to further research the mapping and accounting for spatial variations in nitrogen attenuation capacity. This will allow us to more accurately predict the impacts of agricultural on water quality and to develop landuse patterns that will minimise this impact.

Land Use Land Cover as a consequence and a driver for soil quality changes

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Background and Aims

Land use and land cover changes are directly related to soil use and can therefore be associated to soil organic matter depletion and water contamination with nitrates, as well as to other factors that may alter water and soil quality. Changes in land use are a result of external drivers mainly related to agricultural policies and food requirement increase determining agricultural intensification.

Methods

Data about historical land use land cover uses in Portugal was officially produced covering the last decades. This data was combined with other soil use, agricultural practices integrated in official databases, and potential drivers for soil use change were identified. These integrated datasets were analysed in order to select drivers that better explain soil use evolution and related impacts on soil and water quality in Portugal mainland.

Results

European rules have determined land use and land cover changes over the years according to the European commodities demand, as well as to soil characteristics and agriculture common policy. Many areas have been converted from agriculture to forest and due to the industrialization of agriculture, intensification of crops such as maize, rice and tomato have taken place. Urban areas have increased in number and in area and this resulted in the creation of artificial areas with corresponding soil and water degradation. These are mainly due to real estate speculation and road network expansion. Permanent crops such as vineyards and olive orchards were first abandoned and recently their installation as been encouraged as a tool for sustainable soil use. All soil use changes have resulted in soil organic matter and water quality depletion, with associated nitrate losses and expansion of number and area of nitrate vulnerable zones, as well as the increase of hectares with desertified soil.

Conclusion

Land use and land cover has changed mainly according to EU Directives rules and has resulted in both agricultural intensification and forest areas expansion. This has resulted in soil quality depletion and water quality decline, namely by nitrate pollution and by the increase in desertified areas.

Acknowledgement (optional section) (Max 20 words)

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WATERPROTECT: Innovative tools enabling drinking water protection in rural and urban environments

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The overarching objective of the H2020 project WATERPROTECT is to contribute to effective uptake and realisation of agricultural management practices and mitigation measures to protect drinking water resources. WATERPROTECT will create an integrative multi-actor participatory framework including innovative instruments that enable actors to monitor, to finance and to effectively implement management practices and measures for the protection of water sources.

We propose seven case studies involving multiple actors in implementing good practices (land management, farming, product stewardship, point source pollution prevention) to ensure safe drinking water supply. The seven case studies cover different pedo-climatic conditions, different types of farming systems, different legal frameworks, larger and smaller water collection areas across the EU.

In close cooperation with actors in the field in the case studies (farmers associations, local authorities, water producing companies, private water companies, consumer organisations) and other stakeholders (fertilizer and plant protection industry, environment agencies, nature conservation agencies, agricultural administrations) at local and EU level, WATERPROTECT will develop innovative water governance models investigating alternative pathways from focusing on the ‘costs of water treatment’ to ‘rewarding water quality delivering farming systems’.

Water governance structures will be built upon cost-efficiency analysis related to mitigation and cost-benefit analysis for society, and will be supported by spatially explicit GIS analyses and predictive models that account for temporal and spatial scaling issues. The outcome will be improved participatory methods and public policy instruments to protect drinking water resources.

Innovative monitoring methods for high resolution quick scans of water quality

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Water systems are critical to human and ecological survival. With climate change and urban development, these systems are changing faster than ever. Sustainable water systems requires coherent policies that can achieve environmental objectives. However, a big challenge is to understand how the implementation of EU directives can be achieved at a local level in the North Sea Region. The Interreg project Water Co-Governance for Sustainable Ecosystems project (WaterCoG) aims to demonstrate that the implementation and integration of various water management frameworks can be achieved while also providing social, economic and environmental benefits that are currently not being realized. Innovating participating monitoring tools can be useful to achieve this goal.

Currently, the status of ecosystems and monitoring of nutrient levels are judged by a single measurement without regard to the spatial and temporal variability of water quality and ecology, which is expensive, labour-intensive and provides only limited (point sampling) information about the spatial distribution of concentrations. At the same time, the monitoring process and actual stakeholder practices are dealt with in different domains, which creates uncertainties and lack of trust in monitoring and policies developed by modelling results from national scales. Therefore, there is an urgency and need for better, more local and dynamic monitoring methods and technologies. This paper describes a baseline study to assess the current status of surface water bodies and to determine the ambitions and strategies among local stakeholders. Several methods such as using mobile sensors (attached to boats or underwater drones), test strips and mobile apps, bio-monitoring (sediments), ecology scans using underwater cameras, or continuous/static measurements, were applied at multiple locations within multiple water systems in The Netherlands, Indonesia and Denmark (ongoing) are used as case examples of how participatory monitoring could be done.

Results give an indication of values of basic water quality parameters such as turbidity, electrical conductivity, dissolved oxygen or nutrients (ammonium/nitrate). An important outcome was that the collection of random samples may not be representative of a watershed, given that water quality parameters can vary widely in space (x, y and depth) and time (day / night and seasonal).

Innovative/dynamic monitoring methods (e.g. underwater drones, sensors on boats) can contribute to better understand the quality of the living environment (water, ecology, sediment) and factors that affect it. The field work activities, in particular underwater drones, revealed potentials as awareness actions as they attracted interest from all stakeholders involved. This study involved the cooperation with local managing organizations and international partners, and their willingness to work together is important to ensure participatory actions and social awareness. Next phases include the process of adaptation and strengthening of regulations, or for the construction of facilities such as sewage treatment.

Although further research is still needed to fully characterize these processes and to optimize the measuring tool (underwater drone developments/improvements), the method here presented can already provide valuable information about algae behavior and spatial/temporal variability, and shows potential as an efficient monitoring system. The results will be used in the WaterCog project to demonstrate that the implementation and integration of various water management frameworks can be achieved.

This study would not have been possible without the funding of the interreg projects WaterCoG and the long-term support we have received from the several stakeholders in The Netherlands and Denmark.

Mitigating China’s N, P_2O_5 and irrigation water inputs for staple food by potato as staple food

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Potato will become a kind of staple food under China’s government target of 30% of potato consumed as staple food in 2020. It will generate what benefits to China is urgently needed for studying. In present study we analyzed the historical change in Chinese urban and rural resident’s staple food and potato consumption from 1980 to 2012; estimated the potential effect of potato staple food on rice and flour consumption in different scenarios in 2020, namely business as usual (BAU), potato completely substitute for flour ($30S_{0R+100F}$), 50% potato substitute for rice and others substitute for flour ($30S_{50R+50F}$) and potato completely substitute for rice ($30S_{100R+0F}$); finally evaluated the possible effect of potato staple food on chemical fertilizer N, P_2O_5 and irrigation water inputs for three crops and the planting of early rice and winter wheat in different scenarios. The results showed that, per capita potato consumption will change from 7.7 and 14.5 kg yr^{-1} to 7.1 and 11.6 kg yr^{-1} for urban and rural residents during 2012–2020, respectively, but mostly fresh vegetables. Per capita more 2.9 and 4.7 kg potato per year will enter staple food diets in 2020 under our government’s target, accounting for 2.6% and 3.1% of the weight of per capita rice and flour in urban and rural areas. Potato staple food is expected to reach 5.2 Tg, accounting for 3.1% of total rice and flour consumption in 2020, equals to substitute for 4.2–8.5 Tg wheat grain and 5.1–10.1 Tg rice grain in different substitute scenarios. The reduction in rice and wheat grain means we can decrease 5.5–11.2% of winter wheat sowing on the North China Plain or 12.4–24.6% of early rice sowing. In addition, total chemical N, P_2O_5 inputs and irrigation water for three crops can be reduced by 0.2–0.3 and 0.1–0.2 Tg and 1.8–4.6 billion m^3 in different scenarios relative to BAU, the saved irrigation water equals to 4.0–10.3 million people’s comprehensive water use in 2015. But the above benefits closely rely on our government’s incentive policy and advocacy, and the acceptance of potato food products of the public in China.

Table 1. Staple food rice and flour, rice and wheat grain substituted by potato as staple food, and the demand of rice and wheat grain in different scenarios in 2012 and 2020 (Tg yr^{-1}).

Scenario	Rice	Flour	Potato staple	Substitute rice	Substitute flour	Substitute rice grain	Substitute wheat grain	Rice grain demand	Wheat grain demand
2012	105.1	70.3	0.0	/	/	/	/	204.0	114.4
BAU	100.1	74.9	5.2	0	0	0	0	194.6	121.9
$30S_{0R+100F}$	100.1	69.6	5.2	0	5.2	0	8.5	194.6	113.4
$30S_{50R+50F}$	97.4	72.2	5.2	2.6	2.6	5.1	4.2	189.5	117.7
$30S_{100R+0F}$	94.8	74.9	5.2	5.5	0	10.1	0	184.5	121.9

Environmental assessment of livestock farms in the context of BAT system introduction in Russia

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Currently the reforms of environmental legislation are in progress in Russia. They provide among other things the incentives for farms, the environmental activity of which includes introduction of BAT. The creation of Russian BAT reference books on Intensive livestock farming also continues. It is assumed to use the existing versions of relative European BREF as an analogue.

One of the debating points in this work is assessment and rating of emissions since special targeted studies aimed at determining the emission factors of livestock farms and the rated values of hazardous gases emissions from agricultural sources have not been recently conducted in Russia. The valid Russian regulatory and legislative documents specify the normative values of ammonia, carbon dioxide, and hydrogen sulfide concentration (not emission) as well as dust content in the air of livestock houses. They also set the values for maximum concentration of harmful gases within the sanitary zones of farms (300-2000 m depends the farm type).

The criteria and indicators for farm assessment must be easily understood by both scientists and farmers; they have to be comparable, measurable and formalizable. The testing results of the calculation methodology of nitrogen balance for agricultural enterprises in Leningrad Region showed that nitrogen use effectiveness (NUE) as an integrated index of environmental load meets such requirements.

The viability of manure storage and spreading techniques recommended by European BREF, namely compost heaps covering and immediate ploughing of organic fertilizers after spreading, was estimated on the example of an agricultural enterprise of mixed type (crop-animal production farm) in Leningrad Region with 3000 ha of farmland and 718 cows with the milk yield of 7000 kg/year. The estimated value of reduced total nitrogen losses and lower input of mineral fertilizers owing to higher nitrogen content in field-applied organic fertilizers can be 20%. According to the calculation results of the farm-gate balance for this farm the value of nitrogen surplus is 48.3 kg/ha, which is below the limit values and indicates the possibility to increase the application amount of nitrogen fertilizers. However, the value of the coefficient of nitrogen use efficiency NUE=0,21 is significantly below the European average.

For the rough assessment of technologies on the initial stage of Russian reference books creation it is practicable to use the data from EU BREF on intensive rearing of pigs and poultry

When farms are assessed on the stage of integrated permits issue it is feasible to use the measured air concentrations of hazardous substances along with the estimation whole-farm environmental impact by nitrogen use efficiency.

Abatement of ammonia emissions from dairy cow house concrete floor surfaces under simulated north-west European conditions

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Background

Winter housing of dairy cows and beef cattle is common practice in north-western (NW) European countries such as the UK and Ireland. In 2014, a third of agricultural NH_3 emissions in the UK were derived from housing and hardstanding surfaces, making these the largest source of NH_3 emissions from the manure management chain. Following mechanical scraping of concrete walkways in dairy/cattle houses, a thin film of slurry (c. 2 mm) is left behind from which NH_3 emissions continue. The application of additives to this emitting layer has the potential to significantly reduce NH_3 volatilisation from cattle housing surfaces by abating the peak NH_3 flux associated with urea hydrolysis which occurs approximately 1-6 hours after excreta deposition.

Methods

A dynamic flow-through chamber based study (**Fig. 1**) was carried out to determine the NH_3 abatement potential of 10 additives applied to dairy cow urine (0.8 kg) and dung (1.2 kg) covering a concrete surface (1 m^2) in order to simulate the 2mm layer of slurry left behind after scraper operation. NH_3 emissions were monitored for 24 hours following excreta and additive application, with 4 experimental runs conducted for each additive. The experimental temperature was set at 12°C, a temperature considered representative of NW European winter housing conditions. In *Part 1*, fresh urine was used with an average urea-N concentration of 4 g L^{-1}, likely due to urea hydrolysis during the excreta collection period. In *Part 2*, artificial urea was used to increase urine urea-N concentration to c.8 g L^{-1}.

Results and Conclusions

Peak NH_3 fluxes from fresh dairy cow slurry, applied as a 2mm layer on concrete surfaces, occurred at approximately 3-5 hours post application, peaking at 133 mg NH_3-N m^{-2} $hour^{-1}$.

Of the 10 additives tested (**Fig. 2**), 6 showed no significant difference in NH_3 emissions compared with the control treatment at 6, 12 or 24 hours after excreta and additive application over the 4 experimental runs. These 6 additives were clinoptilolite (zeolite), eugenol, Agrotain (NBPT; urease inhibitor), LIMUS (NBPT+NPPT; double urease inhibitor), Envirobed (paper bedding) and sawdust.

Acidifiers offer the most potential for cost-effectively abating NH_3 emissions from dairy/cattle housing surfaces by increasing the NH_4^+:NH_3 ratio. Experimental data suggests that targeting a slurry pH of 6 at the housing floor stage can significantly reduce NH_3 emissions from fresh excreta. Of the tested additives, the acidifier aluminium sulphate (alum) is the most successful at abating NH_3 emissions from slurry both in *Part 1* (4 g urea-N L^{-1}) and *Part 2* (8 g urea-N L^{-1}) of this experiment, particularly after 6 hours (76% NH_3 abatement in *Part 1*, 80% *Part 2*), where the efficacy of alum is greatest relative to the other acidifiers. Alum is followed closely by calcium chloride (69% *Part 1*, 74% *Part 2*) and sulphuric acid (41% *Part 1* with 1.0 M, 69% *Part 2* with 1.5 M). Actisan, a commercially available biocidal bedding disinfectant is another successful NH_3 abatement option, although to a lesser degree (59% after 6 hours in *Part 1*) and at a higher economic cost than the acidifiers (**Fig. 3**).It is proposed that to automate additive application within existing cattle housing, mechanical walkway scrapers, or robotic scrapers, with the capability to spray water in the wake of the scraping action could be adapted to spray liquid additives on walkway surfaces.

Assessment of options to support sustainable intensification of grazed grasslands

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Introduction

There is increasing pressure on the agricultural sector to reduce its negative impact on the environment through the emission of greenhouse gasses (GHG), and eutrophication of ground and surface waters. In Ireland, the agriculture sector has a strategy Food Wise 2025 to dramatically increase milk production in response to the end of milk quotas. But agricultural expansion has to be coupled with achieving national reductions in GHG emissions, nutrient loss to water and ammonia emissions. In order to develop grassland management strategies that are both environmentally friendly and economically sustainable, it is imperative that individual mitigation measures for N efficiency are evaluated for cost-effectiveness.

Methods

A model was developed to evaluate a range of intensification scenarios. The model dynamically links the Moorepark Dairy System Model, with a grass growth module and a number of nitrogen (N) loss modules to simulate the effect of farm management on N efficiency, N losses, production and economic performance. The model includes the option to assess the effect of using nitrification and urease inhibitors. It has been designed in such a way that the emission factors can be adjusted or refined (e.g. soil type, seasonality) based on the latest research data. We applied the model to assess a number of intensification scenarios to increase production and reduce N losses.

Results

The intensification scenarios indicated that grassland yields could be increased from 10.1 to 13.9 T DM ha^{-1} yr^{-1} resulting in a 59% per hectare increase in milk yield. Fertiliser N inputs ranged from 160 to 250 kg N ha^{-1} and resulted in increased N losses from 107 to 185 kg N ha^{-1}. Ammonia volatilisation was the largest loss pathway ranging from 50 to 90 kg N ha^{-1}. The use of inhibitors reduced N loss by leaching by 37%, N_2O by 31% and reduced the N foot print of milk from 12.8 to 10.1 kg N t^{-1} milk.

Conclusions

Milk production could be increased by 50-60% using a range of management practices. The N foot print of milk can be reduced but total emissions increase compared to baseline. The nitrification and urease inhibitors resulted in the lowest N losses and milk N footprint.

Acknowledgements

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Changes of nitrogen flows in Swiss agriculture – drivers and consequences

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Nutrient flows in Swiss agriculture are strongly influenced by livestock production. In 2014, for example, approx. 80% of the nitrogen (N) in sold agricultural products came from livestock products. About ¾ of the N inputs into livestock production came from Swiss grassland and arable crop production and about 80% of the N outputs of livestock production were used as fertilizers for grassland and arable crops. Manure thus contributed ¾ of the N fertilizer inputs into crop production. On the other hand, almost 50% of the N in external resources bought by the farmers was feed for livestock. If external inputs from N fixation and deposition are also included, about 40% of the imported resources came from the atmosphere and 30% each from feed and fertilizers. These numbers are based on farm-gate N balances for Swiss agriculture according to the OSPAR guidelines. In addition, manure N production was estimated as the difference between N in feed intake and N in animal products. On the emission side, 90% of the agricultural and over 80% of total ammonia (NH_3) emissions came from livestock production and manure management. This domination of the agricultural nutrient household by livestock production is mainly due to the high share of grassland (70% of the utilized agricultural area).

Livestock production always had a leading role in Swiss agriculture. Between 1990 and 2014, however, the contribution of manure to total fertilizer N inputs into crop production increased from 69% to 75%, mainly because mineral fertilizer N inputs decreased by about 25%). Nevertheless, N export in crop products increased by over 40%. Thus, the N use efficiency (N in exports / N in imports; NUE) of Swiss agriculture increased from 0.23 to 0.31, in spite of the nearly 100% increase of protein imports in feed. However, this improvement was much less impressive than for phosphorus where fertilizer imports decreased by 75% and the use efficiency increased from 0.22 to 0.63. A major driver for this improvement was the introduction and enforcement of strict nutrient balance restrictions for N and P. This nutrient balance is part of a wider policy program in which direct payments were partially linked to good practice with regard to the positive effects of agriculture on ecology and animal welfare. Other aspects of good agricultural practices included an adequate share of biodiversity surfaces, a planned and strict crop rotation, adequate soil protection, a particular choice and application of pesticides as well as animal friendly livestock production. A voluntary agri-environmental scheme with financial incentives to promote integrated production (IP) was introduced in 1993. In 1998 the measures were labelled ‘‘Proof of Ecological Performance’’ (PEP) and were made conditional in a cross-compliance mechanism, meaning that direct payments are reduced if PEP requirements are not met. Thanks to the incentive approach over five years, farmers quickly adopted the new requirements in spite of strong initial fears of crop yield losses. Thus, most of the achievements mentioned above for 1990-2010 were actually reached by 2000 already. Since then the situation, especially fertilizer inputs remained quite stable because (most) farmers complied with the set limits but had no reason to improve further. Incentives are needed to motivate farmers to aim for a continuous optimization rather than just fulfilling fixed limits over decades. This approach was adopted with the introduction of regional "resource programs" in 2008 with timely restricted financial support for clearly defined improvements, e.g. the introduction of low emission slurry spreading techniques. A gradual improvement of the NUE could also be a promising aim for such programs, as it is known that potential still exists on practically every farm.

Environmental Assessment of Nutrient flows for livestock supply chains

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Background and aims

The Livestock Environmental Assessment and Performance (LEAP) Partnership is a multi-stakeholder initiative involving governments, private sector, and civil society organisations and non-governmental organisations, with the Secretariat hosted at the Food and Agriculture Organization of the United Nations. Its objectives include to develop comprehensive guidance and methodologies to assess the environmental performance of livestock supply chains, built on consensus. The methods are based on the life cycle thinking and eco-efficiency concept. Amongst the LEAP outputs are guidance documents on the environmental assessment of various livestock supply chains (e.g. large ruminants, small ruminants, pig and poultry) with a focus on climate change[2]. The scope of the project is currently being broadened to include amongst others work on (a) accounting of nutrient and water flows and (b) assessment their potential impacts. We report on the main aspects developed for the “nutrient” guidelines.

Methods

A Technical Advisory Group (TAG) on environmental assessment of nutrient flows in livestock supply chains was set-up by the LEAP secretariat in early 2016. The TAG consisted of 35 members from all continents and stakeholder groups. Two face-to-face and several web-meetings were held to build consensus on methodologies and concepts recommended in the guidelines. The draft guidelines were submitted in February 2017 to the LEAP steering committee and will undergo peer-review followed by a public consultation in spring 2017.

Results

Key aspects covered by the guidelines include:

- Comprehensive analysis of nutrient flows along the supply chains with recommendations on quantification methodologies including flows for primary processing and post-primary processing (e.g. sewage); accounting for specific N and P flows and spatial redistribution and losses associated with housing and grazing system practices; N and P flows and losses from background processes (including fertiliser production) and transportation.
- A proposal for refinement of the existing methodology for allocation of nutrients between manure from livestock supply chains and between multiple crops.
- Consensus on impact assessment methods covering eutrophication potential (terrestrial, freshwater and marine) and acidification (terrestrial and freshwater) for global relevance.
- Life-cycle Nutrient Use Efficiency as an additional key indicator for nutrient assessment.
- Other nutrient indicators to help with interpretation of the results: nutrient surplus, nutrient footprints, and circularity indicators.

Conclusions

The guidelines for the environmental quantification of nutrient flows and impact assessment in livestock supply chains significantly improves previous guidelines and recognizes the importance of nutrient cycles at different scales. It will facilitate valorisation of nutrients in livestock systems to improve efficiency of production and minimise negative environmental impacts.

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[2] http://www.fao.org/partnerships/leap/en/

Nitrogen Europe’s agri-food system and its consequences on environment and human health

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Food production and dietary patterns are increasingly wasteful, characterized by health inequality, and cause huge environmental costs. Achieving a trend reversal is one of the big challenges of the 21st century and requires the integration of environmental protection, human health, and food security in a future agri-food system. The wasteful dietary patterns in the EU agri-food system create high nitrogen losses, resulting in considerable impacts on climate change, air quality, water quality, soil quality and biodiversity[1]. At the same time, diets are characterized by low nutritional value and lead to an increasing burden of chronic diseases in the European Region[2]. A reduction in animal protein, but also in innutritious “empty” calories offers potential to optimize diets in respect to both nutrition and environmental criteria. Application of mitigation technologies and implementation of good farming practice can help improving the nitrogen use efficiency of the whole agri-food system. On the other hand, nitrogen mitigation target cannot be reached without dietary changes towards plant-based option, alternative foods and reduced food waste[3].

We will review current literature linking policy interventions on sustainable diets (such as reviewed by [5]) and dietary choices (e.g. current diet, vegetarian diet, vegan diet) with the environmental consequences linked to losses of reactive nitrogen these diets cause. The presentation will frame some overarching questions relating the agri-food system with the nitrogen cycle, i.e. (i) How far can losses be reduced by technological options and how much emission reductions need to come from behavioural changes? (ii) What is the role of waste reduction? (iii) What are the direct (via nutrition) and indirect (via pollution) health effect of diets?
These questions will be assessed more in detail in an upcoming report by the Expert Panel on Nitrogen and Food (EPNF) under the Task Force on Reactive Nitrogen, UN-ECE Convention on Long Range Transboundary Pollution (CLRTAP) [4,2].

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The Danish nitrogen footprint - Applying nitrogen footprints and using policy scenarios to change consumption behaviour

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Background and aims

Over the last century, human activity has reshaped the global nitrogen (N) cycle, so that the anthropogenic changes to the N cycle already has crossed the safe operating space for stability of Earth system processes. For this reason, a suite of responses: consumer and ag-management driven and integrated policy solutions is needed to achieve N source control and mitigation of the unintended consequences of excess reactive N. In this paper, the first approach to the Danish N footprint model is presented to build awareness of protein consumption and embedded N in the Danish society.

Methods

The N footprint is a calculation of the N embedded in our everyday consumption of food, energy, transportation and services & goods. The N footprint methodology was developed by the N footprint team: http://www.n-print.org/, where the definition of a N footprint was first outlined: "*the total amount of reactive nitrogen released to the environment as a result of an entity's resource consumption, expressed in total units of reactive nitrogen*". In this Danish study, the N footprint is calculated based on food intake (i.e., FAO estimates of protein, food supply and food waste) and the amount of N lost during the production of that food, which is presented as Virtual N Factors (VNF), which include losses such as fertilizer not incorporated into the plant, crop residues, processing waste, etc. The energy component of the N footprint (i.e., N released from fossil fuel combustion) is calculated using average rates of energy consumption and country-specific emission factors for Denmark.

Results and conclusions

The Danish N footprint is still under development, preliminary results (using VNFs from Netherlands with Danish data) show many similarities with comparable European countries. The average Danish N footprint is comparable with the N footprint reported for Germany and the Netherlands, which was around 25 kg N capita^{-1} yr^{-1}. This study aimed at further developing VNFs for Denmark, for a comprehensive average footprint calculation. The scope of this paper is also to assess different ways of reducing the Danish N footprint, e.g. through evaluations of how different agro-environmental regulations and policy scenarios affect the N footprint. The policy scenarios will be used to investigate whether different agro-environmental regulations and policies can have an impact on the N-footprint. Emphasis will be given to investigate impact of different policy interventions with regard to minimizing the N footprint. Examples are: i) Through supports for more organic production; ii) how waste water treatment can reduce the footprint (policies on recirculation of biosolids); iii) how different energy and transportation policy scenarios effect the footprint, and iiii) how policies towards more recirculation of food waste can reduce the footprint. Eating less meat, reducing household food waste, flying less, usage of public transport and reduction of energy usage are important actions at the individual level. However, these everyday actions must be combined with political interventions and the political actions, instruments and regulations must be based on the fact that we, as citizens demand that the good N reduction choice also is the easy choice.

The Danish Nitrogen Research Alliance (DNMARK): Research and Know-how for a sustainable, low-Nitrogen food production

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The aim of this poster is to present the Danish Nitrogen Research Alliance (DNMARK) on Research and know-hoe for a sustainable low-nitrogen food production, focusing on the quantification of N flows and solutions scenarios for a more sustainable N use in Denmark. As one of the world’s most agriculture intensive countries, with a long N regulation history, and state of the art monitoring of developments in key indicators for nitrogen losses, -use and –efficiency, Denmark is a case of special interest.

Based on the results and recommendations from the European Nitrogen Assessment (http://www.nine-esf.org/ENA), DNMARK focus on all parts of the N cascade, and demonstrates results both at the landscape scale and the national scale.

Results from the national N-flow and N-balance accounting 1990-2010 have been analyzed, and methods for the downscaling of these results to regional pilot study regions are developed, together with approaches for the integrated assessment and solutions scenario modeling. For this we work with the following three main types of solution scenarios: i) New production chains with a more efficient use and recycling of N, ii) Geographically differentiated N-measures implemented by cost-effective instruments with localized planning and management of agricultural landscapes, and iii) Changed consumption patterns driving land use change and reducing N use.

Nitrogen balance and Nitrogen Efficiency as an indicator for N losses to the environment

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Background

Nitrogen balance estimates the nitrogen surplus from nitrogen inputs to the soil and nitrogen outputs from the soil. It is seen as an appropriate indicator for N losses to the environment. The aim of this study was to determine the nitrogen balance and nitrogen efficiency in long-term stationary experiments related to manure and fertilizers.

Methods

The long-term experiments were established at the institute in 1968 and in 1983. The studied soil is the most typical soil of the area: soddy podzolic sandy-loam soil *(Albeluvisols/Glacial Till, WRB 2006).* The long-term field experiment 1 "Effect of long-term fertilization systems on the productivity of grain-row crop rotation and the soddy podzolic soil fertility" included 16 treatments with different rates of manure or mineral fertilizer or the combination of the two (N 0-150 kg/ha annually). The long-term field experiment 2 "Effect of liquid manure on perennial grass under long-term application" included 6 treatments: nil inputs, liquid manure with N300, N400, N500, N700 kg/ha, mineral fertilizers with N300PK kg/ha annually. N balance and nitrogen efficiency were calculated: *N balance (kg N ha^{-1}) = N input –N output; N efficiency, % = (N recovered in fertilized crop (kg/ha) - N recovered in unfertilized crop (kg/ha)x100/total weight of N applied as fertilizer (kg/ha).*

Results

According to the calculated N balance for the long-term field experiment 1 the total N input (excluding non-symbiotic N fixation) for the first 7 cycles of the crop rotation was equal to 1036-5311 kg N ha^{-1} (37.0-189.7 kg N ha^{-1} yr^{-1}), depending on the type and the rates of the manure/fertilizer. N accumulated by the crops for the same period amounted to 1351-2346 kg N ha $^{-1}$ (48.3-83.8 kg N ha^{-1} yr^{-1})**.** The N balance for the different treatments of the experiment was changing from -11.3 kg N ha^{-1} yr^{-1} (implying additional N inputs, e.g. atmospheric N deposition, non-symbiotic N fixation) to 105.9 kg N ha^{-1} yr^{-1} (implying substantial N losses). In the long-term field experiment 2 the N balance for the different treatments was: nil inputs - 34.9 kg N ha^{-1} yr^{-1}, liquid manure (LM) N300 +214.2 kg N ha^{-1} yr^{-1} , LM N400 + 302.1 kg N ha^{-1} yr^{-1}, LM N500 +388.5 kg N ha^{-1} yr^{-1}, LM N700 +575.1 kg N ha^{-1} yr^{-1}, N300PK + 205.6 kg N ha^{-1} yr^{-1} . Accordingly, the nitrogen efficiency was low: 29, 24, 22, 18, and 28 %. This indicates a significant loss of nitrogen to the environment.

Conclusions

Nitrogen balance and nitrogen efficiency are important indicators of agricultural production systems efficiency and N losses to the environment. The results of field experiments show that nitrogen losses significantly increase with increasing fertilizer/manure rates.

DPSIR Approach to Nitrogen Management in an Irrigated Agricultural Land

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Irrigation and fertilizers are two of the major inputs of modern agriculture. Nitrogen (N) as a fertilizer source is globally used in crop production. However, its dynamics, cycling and transport in plants and ecosystems are always complex, especially when accompanied with irrigation water. Nitrate (NO_3) form of N is very mobile in soil, it can easily be leached to water bodies resulting in related pollution risks on health, environment and agricultural systems.

There are approaches to quantify the level of NO_3 loss in water resources at catchment level. For example, temporal and spatial NO_3 monitoring allow to identify the level and load of NO_3 in soil, plant, water and food; then these actual data is often used in modelling studies to simulate NO_3 status of the ecosystems. The scientific and practical findings are meaningful when critically evaluated and used in training of farmers and citizens to establish an environmentally sound agriculture. Thus, the objective was to develop a DPSIR (driver-pressure-state-impact-responses) approach to define the catchment level N management system.

The research area Akarsu Irrigation Catchment (9,495 ha) is located in the Mediterranean coastal region, comprising the most intensively cropped and irrigated area of southern Turkey. The soil, plant, crop yield, water (irrigation, rainfall, groundwater and drainage waters) parameters were spatially and temporally monitored from 2007 to 2016 by sampling, measuring, analyzing, data processing, N-budgeting and J2000S-modeling. DPSIR approach was applied; each of the driver, pressure, state, impacts and response were determined and discussed.

Based on the results N is one of the major component of the system either as input or output.

Total of 29 to 65 kg N ha^{-1} y^{-1} leached to drainage, while 70 to 130 kg residual mineral N ha^{-1} stayed in the soil profile. The 9 years' overall results were evaluated by using DPSIR approach (Fig.1). Agriculture, climatic drought and related land use practices are the vast drivers to have pressure on excess fertilizer and irrigation water use and changes in cropping patterns. As a result of pressures, water and soil quality parameters have been quantified while states of human health and air quality have not been measured in this research.

The specific impacts were grouped as environmental, economical and social to lead the officials to make related policies. Therefore, well-established fertilizer and irrigation water management plans in macro (field) and meso (district) scales may help to reduce NO_3 pollution in drainage in the Mediterranean irrigated areas.

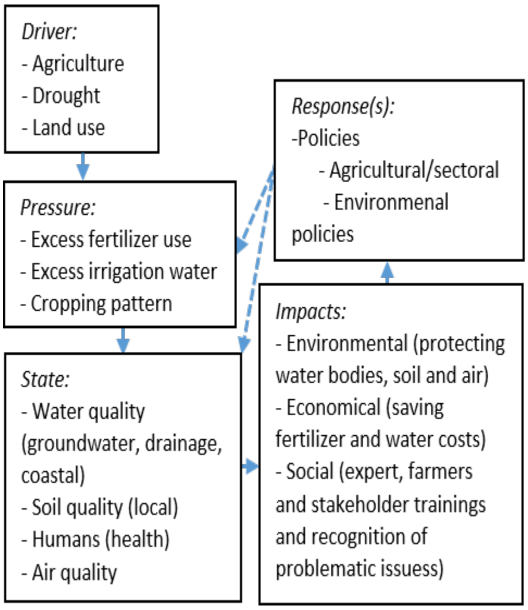

Fig. 1. Application of DPSIR approach in Akarsu Catchment.

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Soil moisture effects on the codenitrification of N_2O and N_2 from a urea-affected pasture soil

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Background and aims

Nitrous oxide emissions from grazed grasslands contribute significantly to anthropogenic N_2O emissions. Emissions of N_2O result from microbial transformations of N substrates. A further significant consequence of denitrifying mechanisms is the production and loss of dinitrogen (N_2) resulting in reduced N use efficiency. The role of codenitrification in N_2 and N_2O losses from pasture systems is poorly studied with gross N gas fluxes often only identified by default via the application of N balance methods. The aim was to improve our understanding of the role codenitrification plays in N_2O and N_2 emissions from pasture soil.

Methods

We investigated the effect of soil moisture on the codenitrification of N_2O and N_2 using repacked soil cores. Treatments consisted of two levels of soil moisture, simulating 'near-saturation' and 'field-capacity', and two levels of urea, (0 and 1000 kg N ha^{-1}), simulating nil and high rates of urine deposition, replicated 4 times. Urea was labelled with ^{15}N to facilitate determination of the source of inorganic-N, N_2O, and N_2, and to allow the contribution of codenitrification to be calculated. Nitrous oxide and N_2 fluxes were regularly determined over a 63 day period while soil inorganic-N concentrations were measured at periodic intervals.

Results

Soil inorganic-N dynamics were typical of those observed under ruminant urine patches. The average daily codenitrification N_2 fluxes under urea were 5-fold higher for soil at near-saturation compared with soil at field-capacity, 0.38 (0.15) g N m^{-2} d^{-1} and 0.07 (0.01) g N m^{-2} d^{-1}, respectively. For N_2, the contribution of codenitrification as a proportion of total denitrification (codenitrification plus denitrification) did not vary with soil moisture, with codenitrification contributing up to 25% of the total denitrification flux. Fluxes of N_2O associated with codenitrification were relatively low, when compared to N_2 fluxes, and were 87.2 mg N_2O-N m^{-2} d^{-1} at near-saturation, comprising 20% of the total N_2O flux. While codenitrified N_2O fluxes at field capacity were extremely low and never rose above 1.7 mg N_2O-N m^{-2} d^{-1}.

Conclusions

This study confirms the role of anaerobic soil conditions in enhancing codenitrification fluxes under ruminant urine deposition. It also demonstrates for the first time that high levels of NO_2^-, or other transitional N compounds ensuing from NO_2^-, also contribute to codenitrification. More detailed soil studies are now required to identify the compounds and organisms involved in codenitrification.

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Fungal and bacterial contributions to codenitrification emissions of N_2O and N_2 following urea deposition to soil

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Introduction

Nitrous oxide (N_2O) is both a greenhouse gas and ozone depleting substance. Grazed pastures contribute significantly to anthropogenic emissions of N_2O but the respective contributions of bacteria and fungi to codenitrification in such systems are unresolved. The objective was to examine the relative codenitrification contributions of bacteria and fungi under a simulated ruminant urine event. It was hypothesised that fungi would primarily be responsible for both codenitrification and total N_2O and N_2 emissions.

Methods

In a laboratory mesocosm experiment, the effects of a bacterial inhibitor (streptomycin), a fungal inhibitor (cycloheximide), and combined inhibitor treatments were measured on soil that had received ^{15}N labelled urea. Soil inorganic-N concentrations, N_2O and N_2 gas fluxes were determined over 51 days.

Results

On days 42 and 51, when nitrification was actively proceeding, all treatments inhibited nitrification as evidenced by increased soil NH_4^+ concentrations and decreased soil NO_2^--N and NO_3^--N concentrations. A decrease in the NH_4^+-^{15}N enrichment occurred under fungal inhibition. Fungi dominated N_2O production: total N_2O fluxes and the contribution of codenitrification to total N_2O fluxes were reduced by $\geq$ 66% and $\geq$ 42%, respectively, with the magnitude of these reductions greatest soon after detectable NO_2^- formation (day 42). Total fluxes of N_2 also comprised a codenitrification component, with greater total N_2 fluxes later in the experiment (day 51), presumed to be the result of greater N_2O reductase activity.

Conclusions

Inhibition of nitrification in a pasture soil by cycloheximide is intriguing and requires further study to identify the organisms and pathways affected. Fungi, not bacteria, dominated total N_2O fluxes, and the codenitrification N_2O fluxes, from a pasture soil affected by urea application.

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Temporal and spatial variations in groundwater quality resulting from policy-induced reductions in nitrate leaching to the Rabis Creek aquifer, Denmark

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Background and methods

The effect in groundwater of political actions aimed to reduce nitrate leaching was assessed by analysis of twenty-five years of groundwater quality monitoring data from a sandy unconfined aquifer. Data were collected from eight multilevel samplers along a ~3 km transect, along the general direction of groundwater flow. Each multilevel sampler comprises 20 very short screens with a 1 m vertical distance from near the water table downwards. The transect covers areas of livestock, plantation & heath, and agriculture. The history of nitrate leaching to the aquifer was assessed using data from the screens close to the water table below the agricultural areas. A 2D reactive transport model of was used to pinpoint the most important geochemical processes.

Results

Nitrate concentrations of infiltrating 'agricultural' water peaked at 100-175 mg-NO_3/L (30-45 mg-N/L) in the year 1989, and then gradually decreased and stabilized at 15-50 mg-NO_3/L (3.5-15 mg-N/L) from year 2000. No or only very low nitrate concentrations were found leaching from the plantation and heath areas. Local farmers declare having used the maximum fertilization rate allowed during the period. Some farmers followed other incentives and sold tilled areas that were transformed into nature preservation areas where all fertilization was terminated, though with some grazing livestock. The timing of the observed decreases of nitrate under the different land use changes therefore suggests a direct link to the political action plans implemented in the same period. Parallel to the development in nitrate leaching, although with a transport time lag, the average concentration of nitrate in the oxic zone of the aquifer was roughly halved between 2000 and 2013. The oxidized and reduced zone of the aquifer is separated by a <1 m redoxcline. At the redoxcline pyrite oxidation, as the absolute dominating nitrate reducing process, releases N_2, sulfate and Ni, while most Fe is precipitated. The released sulfate down-gradient act as a tracer for historical nitrate loadings to the aquifer, due to slow sulfate reduction rates. In agricultural recharge, nitrate frequently explained more than half of the major ions. Thus agriculture was a major determinant for the overall groundwater quality, even subsequent to denitrification. Sulfate concentrations currently increase in the furthest down-gradient part of the transect, carrying the legacy of the former nitrate infiltration.

Conclusions

The spatiotemporal distribution of nitrate and sulfate in a single aquifer could be linked to its nitrate loading history, as caused by the political action plans. Ni contamination (>20 µg/L) by pyrite oxidation could be directly linked to nitrate leaching. Finally, the study demonstrates how, popularly speaking, every farmer makes his own groundwater quality!

Adaptation by farmers to mandatory reduction of fertilizer application rates to crops in Denmark

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To reduce nitrogen (N) leaching from agriculture, N quotas were implemented by Danish legislators in 1991. The N quotas were initially defined as the economically optimum level of N application to specific crops. However, in 1999, a 10% reduction of N quotas below the economically optimal level was required. Due to a number of changes at national as well as at crop scale, such as crop cover, suspension of the EU obligatory set-aside in 2008, increased yields, crop- and fertilizer prices and incorporation of the value of protein in the economic optimum, the reduction had increased to approximately 20% in 2015.

Although quotas are defined at field level, they are administrated at farm level. Thus, an annual N quota at farm level is calculated by adding up the N quotas for each crop in the particular crop rotation of the specific farm. Farmers can freely distribute the farm N quota between the crops grown at the entire farm area, which means that they can apply N at levels exceeding the crop quotas to individual crops as long as they reduce the amount of N to other crops.

In order to assess and evaluate the effect of the system of suboptimal N quotas, investigation of how farmers have adjusted their N application is a useful parameter. Application rates for fertilizer and manure have been recorded at field level since 1990 within the framework of the Danish Agricultural Monitoring Programme. Thus, 25 years of data on five 4-13 km^2 catchments are available, including approximately 120 farms and 1500 fields, allowing a unique assessment of how farmers have distributed their N quotas to optimise farm practices under a suboptimal N quota system.

We will present the concept, methodology and development of the Danish N quota system and describe how the farmers affected by the Agricultural Monitoring Programme adjusted their fertilizer application to observe the mandatory reduction of N quotas during the period 1998-2016.

The Automated Cavity Ring Down Spectroscopy Usage for Nitrous Oxide and Ammonia Emissions Measurements from Soil Using Recirculation and Closed Chamber Systems

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The nitrous oxide give 60% of Latvia greenhouse gas emissions from agricultural sector. Majority of nitrous oxide come from manure management and mineral fertiliser's application. Nitrous oxide emissions from soils is strongly correlated with soil moisture and temperature. Since nitrous oxide have very low concentrations there is risk to overestimate or underestimate nitrous oxide emission. The ammonia emission reduction is one of environmental aims in Latvian agricultural sector. The one of key source is carbamide or urea application. Automated cavity ring down spectroscopy is new technology and there is need for proper methodology estimation.

The aim of this study is to identify optimal measurement time of nitrous oxide and ammonia emission from soil using automated cavity ring down spectroscopy (CRDS) with recirculation and closed chamber systems. First experiment was made in laboratory with controlled climate conditions. The automated CRDS device Picarro G2508 were connected in closed recirculation system with chamber of total volume 2 litres. Dray soil samples were weighted in containers and added different amount of water and ammonium nitrate, totally 49 samples. Each sample were measured 10 minutes and the nitrous oxide and ammonia concentrations were recorded for each second. For each sample measurement session where repeated three times. The second experiment was made during summer 2016 in field conditions. The automated CRDS device Picarro G2508 were connected with transparent chamber of total volume 3 litres using teflon tubes. Each chamber were measured 20 minutes, totally 56 measurement points with different soil, tillage and climate conditions. For each measurement point where three repetitions.

The Picarro G2508 build-inn linear regression, quadratic and Hutchinson & Moiser methods were used to calculate nitrous oxide and ammonia emission for different time periods from 30 seconds till 1200 seconds, the determination coefficient over 0.9 where used to estimate proper measurement time for each sample.

The results of research show quite high variation of nitrous oxide and ammonia emission. Analysed data show that measurement time for nitrous oxide have to be established at field and vary from 120 till 600 seconds using recirculation system and from 200 till 800 seconds for closed chamber system as well as linear method can be used to calculate nitrous oxide emissions. However ammonia emissions do not show linear trend and quadratic or Hutchinson & Moiser methods have to be used for ammonia emissions calculations. The measurement time for ammonia emissions wary from 200 till 600 seconds.

Moving towards an integrated system modelling tool for nitrogen management in agriculture

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The industrialization and intensification of livestock farming in recent years originated an increase in animal excreta production. The use of these organic materials as fertilizers is generally associated with emissions of N_2O. In the absence of more specific values, the IPCC recommends the use of default emission factors (EF) for the estimation of direct and indirect N_2O emissions, independent of the fertilizer type, application techniques and land use. As recent studies have highlighted there is the danger of pollution swapping between NO_3^- leaching and N_2O and NH_3 gaseous losses, which requires a holistic approach to the diffuse pollution issue, including the N dynamics and management in the soil-plant-atmosphere systems.

In this study the agricultural system model RZWQM2 was tested in predicting N_2O emissions from a winter oat cover crop (*avena sativa)* amended with slurry in two soils with distinct properties for water retention and conductivity and organic C contents. The model was calibrated and validated against experimental data collected during a period of 4 years in field lisimeters, including soil water and temperature, drainage, N_2O emissions, NO_3^- leaching and weather data.

N_2O direct emissions were estimated with overall efficiencies of 82 and 78 % for the sandy soil and the sandy loam soil respectively; for nitrate leaching, the corresponding prediction efficiencies were 74 and 76 %. Higher cumulative N_2O direct emissions were observed and simulated from the sandy loam soil, while for leaching the opposite occurred. Regarding both type of emission fluxes, results show that there are some errors of peak estimation due to a one day delay or advance in the simulated peak or to an over/underestimation of the peak. The overall emission factors for direct N_2O emissions present values of 0.44 and 0.69 for the sandy and the sandy soils respectively, which are, in average, 50 % lower than the IPCC default. Moreover, the EFs were affected by short-term weather patterns that resulted in major changes in soil water filled pore space.

These results indicate that the system model was sensible to the differences between both soils associated with water dynamics and the organic C content. The overall agreement between the estimated and the measured flux dynamics is very promising considering the dynamics of N in the soil-plant system. These results can be used to set up integral strategies to decrease N emissions from livestock farming systems, taking in account possible synergies and antagonisms of measures on N_2O emissions and NO_3-Leaching. Due to the strong influence of the inter-annual precipitation variability, several years are required to produce robust mean emission factors.

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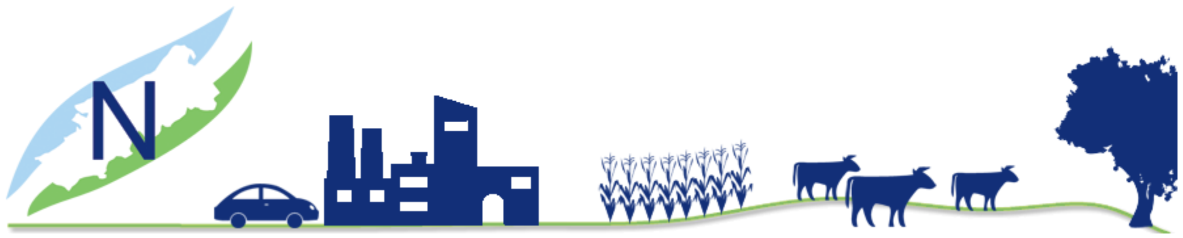
INMS

TFRN LRTAP
Long-range Transboundary Air Pollution



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