# Proceedings of the XXII International Nitrogen Workshop

## Aarhus, 2024

# XXII N Workshop 2024

# Book of abstracts

Proceedings of the XXII International Nitrogen Workshop

Resolving the Global Nitrogen Dilemma - Opportunities and Challenges

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# Forword

More than half of the world's population is nourished by crops grown with nitrogen (N) fertilizers. As global food demand continues to grow in the coming decades, the demand for N inputs and for agricultural land are expected to increase substantially. Unfortunately, too much N in the Earth's soils poses multiple severe environmental and health problems that have yet to be solved. Inefficient N use contributes to global warming, ozone depletion, eutrophication, reduced biodiversity, and aerosols that contribute to air pollution and health problems. From a socio-economic perspective, N losses reduce farmer's profits and affect food security. We are facing a global N dilemma of an unprecedented magnitude: how do we reconcile the need for sufficient N inputs to ensure crop productivity and human nutrition with the need for reducing N losses to sustain a viable environment and healthy ecosystems? Improving N use efficiency, reducing N losses along the food and feed processing chain, and increasing N recycling are key challenges to address this dilemma. There is a large and growing body of knowledge and technological capacity to improve crop N uptake, manage N losses along the food chain, and recycle N from waste streams, but implementation of this knowledge requires cooperation and co-creation among actors and stakeholders including researchers, farmers, advisors, industry, NGOs, and policymakers, and raising awareness that N use in agriculture is a double-edged sword. The N workshop aims to raise awareness of the N related challenges and to share the newest information on innovations and progress on N impact research to develop concrete strategies to dramatically improve N management worldwide. To do so, we not only need to further improve the technological and management options that increase N use efficiency, but even more importantly, we must understand the socio-cultural and economic incentives needed to encourage farmers to adopt such options.

Since 1982, researchers from different parts of the world have regularly gathered at the N workshop in different locations to try to put all the parts of the N puzzle together. The XXII edition of the International N Workshop, hosted by Aarhus University, contributed to solving this challenge by welcoming exciting presentations of more than 350 participants from 36 different countries divided into six regular and four special sessions, together with seven keynotes by outstanding international scientists.

Over 5 days in Aarhus, the participants covered a wide range of topics including field measurements, farm to global N budgets, and food system perspectives, which are summarized in this book of abstracts. We hope that this workshop is a turning point in the N dilemma and makes a decisive contribution to the transformation of agriculture and the agri-food system. We would like to thank all the people who made the XXII International N Workshop possible, including our local staff and helpers, the session leads, members of the scientific committee, the conference sponsors, and all the participants for their contributions.

*Diego Abalos, Klaus Butterbach-Bahl, Hanne L. Kristensen, Jørgen E. Olesen*

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Food systems

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José Mogollón (Leiden University, NL)

Ute Skiba (Centre for Ecology&Hydrology, UK)

Livestock in agricultural systems from a nitrogen perspective

Mariana C. Rufino (Technical University Munich, GER)

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Special session: Nitrogen in organic farming

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Special session: Nitrogen communication

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## 1.1 General keynote: Wim de Vries "Spatial variation in the warming and cooling impacts of anthropogenic nitrogen fixation at global scale"

Wim de Vries is professor at the Environmental Systems Analysis Group of Wageningen University, where he holds the chair "Integrated nutrient impact assessment". He is a researcher in the field of biogeochemistry with special reference to nutrient cycling, soil acidification, greenhouse gas emissions and metal pollution. His research is organized around large scale impacts of the elevated use of nutrients (especially nitrogen and phosphorus) in agriculture on air-, soil - and water quality and related boundaries in view of those impacts. Wim de Vries wrote more than 600 publications as an author or co-author on the above mentioned topic, including ca 200 publications in international peer reviewed journals.

### Spatial variation in the warming and cooling impacts of anthropogenic nitrogen fixation at global scale


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### Abstract

Anthropogenic perturbation of the global nitrogen (N) cycle affects the Earth's climate due to manifold impacts on the N and carbon (C) cycles. Warming effects include (i) N-induced increases in emissions of nitrous oxide (N2O), and methane (CH4) from soils, sediments and water bodies and (ii) NOx emission-induced tropospheric O3 formation, leading to reduced C sequestration in forest biomass and soils. Cooling is caused by N-induced C sequestration in terrestrial and aquatic ecosystems. In this study we assessed the spatial variation in the N-induced warming and cooling effects of N2O, CO2 and CH4 exchange and the resulting net

effect at the global scale using both an empirical approach and a process-based model (DLEM). Calculations were made for 2010 and for 2050 under six future SSP/RCP scenarios combined with N mitigation ambitions.

Results of both the empirical and model-based show the warming impact of enhanced N2O and CH4 emissions combined with the reduced C sequestration in response to NOx emission-induced O3 formation (1.13 Pg CO2-C eq. yr-1) is slightly higher than the global cooling effect of N-induced C sequestration (-0.87 Pg CO2-C eq. yr-1). Results, however, vary strongly in space. Hotspots for anthropogenic N-induced N2O emissions are predicted for China, India, Western Europe and Central US, where agricultural activities were intense.

Significant N-induced CO2 sequestration occurs in southern China, India, South Asia and part of Africa. Changes in N inputs and land use under future scenarios affect both warming and cooling, and the net effect of N use stays relatively similar.

## 1.2 Session 1 - How to increase nitrogen use efficiency

### 1.2.1 Keynote: Ute Skiba "Nitrogen options in Europe and Southern Asia"

Ute Skiba works for the UK Centre for Ecology&Hydrology with a focus on greenhouse gas flux measurements, particularly regarding N2O, NO and CH4 fluxes in natural/agricultural ecosystems and temperate/tropical/arctic climate zones. She studies environmental drivers (climate, soil properties, agricultural management, atmospheric N deposition) and microbial processes leading to emissions of these pollutants to the atmosphere & determine spatial and temporal variability of soil trace gas fluxes and upscaling from plot to region.

#### Nitrogen options in Europe and Southern Asia

Ute Skiba[1*], Nick Cowan[1], Mark Sutton[1], Robert Rees[2], Annie Young[3], Arti Bhatia[4], Prakash Ghimire[5], Rizwan Shahid[6], Mizanur Rahman[7], Sarath Nissanka[8]

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#### Abstract

Synthetic Nitrogen (N) fertiliser application rates differ between Europe & Southern Asia (SA). Europe's N fertiliser rates increased over 1961–1981 & stabilised since 2000. Contrary, N fertiliser use increases steeply across SA countries, with large N application rates (108 kg N/ha) compared to Europe (47 kg N/ha, FAO, 2024). Environmental consequences of N over-fertilisation (N2O, NOx, NH3, NO3) impact air quality, climate change, eutrophication, biodiversity. In response, the EU set targets to reduce 50% of nutrient losses and reduce 20% N reduction by 20301. Advanced mitigation options are available, but not affordable for small farms in Europe & SA. Mitigation options for Europe are: Soil testing to optimise crop needs; macro/micronutrients & soil pH; improve soil organic matter using cover crops; incorporate residues; smart fertilisers; nitrification & urease inhibitors; legume intercropping; riparian buffer strips, etc.

Options for Southern Asia (SA): India's agronomic N policies include recommended N fertiliser application rates across their climate zones2. Urea is the preferred N fertiliser for SA countries, less energy demanding & cheaper compared to i.e. $NH_4NO_3$. In 2015 India switched to urea coated with Neem oil, which serves as a nitrification inhibitor. It reduces $N_2O$, but increasing $NH_3$ emissions. Some smaller SA countries cannot sustain N fertiliser imports, due to economical fluctuations, leading to poor crop yields & poor nitrogen use efficiency. Policies for SA are required to reduce N losses, to improve NUE by: no residue burning, manure for soil but not burning, and no N leakage to rivers, estuaries.

Reference to a journal publication:

[1]Higgins, S., Keesstra, S.D., and 45 authors, 2023. Stocktake study of current fertilisation recommendations across Europe and discussion towards a more harmonised approach. Eur. J Soil Sci. 2023;74:e13422. https://doi.org/10.1111/ejss.13422

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### 1.2.2 Oral presentations

# Challenges and Way Forward to Increase Nitrogen Use Efficiency

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## Abstract

Nitrogen (N) is widely used in agriculture for increasing crop yields and plays an important role in human food and nutrition. But N use efficiency (NUE) is too low (20-40%), while its loss is unreasonably high (60-80%). Excessive and ineffective use of N raises the cost of production and brings manifold threats to the environment. Unexploited reactive N (Nr) degrades soil health, augments environmental menace, and increases greenhouse gas emission that contributes towards global warming and climate change. Therefore, improving NUE in crop production systems is a must for sustainable agriculture and healthy environment. The study attempted to prepare a compendium of available N management options, analyzed their performances and shortfalls, recommended some viable technologies for farmers' practice, and envisaged for future innovative N guidance. The global scientists are in thirst for innovating location specific best management options to raise NUE to a reasonably higher level from the present state that could at least halve N waste. Nitrogen management practices, viz., 3–4 split application, integrated nutrient management, legume-based cropping systems, genetic improvement of crops, nitrification and urea inhibitors etc., are all important techniques to improve NUE. Fertilizer recommendation using an Android-based N apps would be challenging but inspiring. A holistic approach in selecting the guidance considering locally available resources, farmers' interests, economics, and the environment might be effective for better N management and achieving a higher NUE.

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Alam, M.S., Khanam, M., Rahman, M.M., 2023. Environment-friendly nitrogen management practices in wetland paddy cultivation. Front. Sustain. Food Syst. https://doi.org/10.3389/fsufs.2023.1020570

## Optimizing N fertilization in silage maize: consideration of site and management leads to savings compared to official recommendations

Josephine Bukowiecki[1], Larissa Ullrich[2], Martin Komainda[3], Antje Herrmann[2], Insa Kühling[1], Henning Kage[1]

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### Abstract

Fine-tuning of nitrogen (N) fertilization to the difference between plant N demand and soil N supply can decrease N losses from agricultural systems and allow to achieve same yields at lower N rates. This economic and ecological potential is huge in Northern and Western European silage maize (Zea mays L.) cropping systems, being the third most widely grown crop (Eurostat, 2024) and often linked with overfertilization (Ten Berge et al., 2007). Yet, the estimation of optimal N fertilization is particularly challenging for silage maize, as it is typically fertilized by one single-application at sowing.

A large set of German and Swiss silage maize N fertilization trial data was compiled to examine the effect of site and management parameters on the economic optimum N fertilization (Nopt). On the base of 223 different N response functions, an empirical model to predict Nopt was developed.

Four site and three management parameters were found to significantly influence Nopt. When combined in a linear model, they described Nopt with an adjusted R-squared value of 0.29. Approximately half of the variation explained by the model could be attributed to soil and weather parameters, while the other half was explained by pre- and cover crop category and whether the straw of the pre-crop was removed or incorporated. It is demonstrated that a N fertilization recommendation based on these parameters allows for a reduction of N fertilizer of 21 % compared to the current German fertilizer ordinance without yield reduction.

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# Effects of regional patterns, farm structure and drought events on nitrogen use efficiency in Germany between 2017 and 2022

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## Abstract

Nitrogen (N) utilisation must be optimised to ensure food security and mitigate negative externalities of food production. However, studies find substantial differences in N use efficiency (NUE) on the regional and farm type-level, and an increasing number of drought events jeopardise recent trends of increasing NUE in Western Europe. In order to identify drivers of differences in NUE we calculate NUE by considering N input and output parameters at the "farm gate" as system boundary (Löw & Osterburg, 2024; Quemada et al., 2020), based on farm data of the German Farm Accountancy Data Network. Covering around 30,000 NUE observations between the years 2017 and 2022, we develop a panel data model to identify effects of regional patterns, farm structural characteristics and drought events (Finger, 2010). The results indicate an increasing trend in NUE on the sectoral level from 56% to 68%, while 2018 stands out as a year of extreme drought and low NUE. We find a large variance within each farm type, indicating efficiency reserves in N use. Our multiple regression analysis reveals statistically significant interrelations between NUE and independent variables, just like altitude and soil fertility (regional level), or crop selection and manure application intensity (farm structural level). First results on the effect of drought events on NUE indicate a low adaptation of N management to the dry conditions, resulting in lower NUE and thus increasing N emissions. In this context, we highlight the need to adapt practical guidelines addressing N management for farmers that consider the increasing occurrence of extreme weather events.

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Löw, P., Osterburg, B., 2024. Evaluation of nitrogen balances and nitrogen use efficiencies on farm level of the German agricultural sector. Agric. Syst. 213, 103796. https://doi.org/10.1016/j.agsy.2023.103796

Quemada, M., Lassaletta, L., Jensen, L.S., Godinot, O., Brentrup, F., Buckley, C., Foray, S., Hvid, S.K., Oenema, J., Richards, K.G., Oenema, O., 2020. Exploring nitrogen indicators of farm performance among farm types across several European case studies. Agric. Syst. 177, 102689. https://doi.org/10.1016/j.agsy.2019.102689

# Site-specific management zones for crop rotation based on NDVI images of clover-grass fields

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## Abstract

Legumes are a significant source of nitrogen (N) due to their symbiotic relationship with rhizobia, particularly in organic farming. The amount of N-fixation depends on the biomass of legumes produced, which varies due to soil heterogeneity and weather variations (Murphy et al. 2021). The heterogeneity further influences the development of crops within the crop rotation, as the N from the legumes is partly available for the subsequent crop. In this study, three clover-grass fields in north-west Germany were divided each into two management zones (MZ) based on NDVI maps from drone-based multispectral cameras. Simultaneously, the above-ground biomass (AGB) of clover and grass were harvested and weighed. The data about mineral N-stocks in clover-grass and subsequent crop were estimated by soil sampling (depth 0 – 90 cm). In the following crops summer spelt (2021, 2022) and winter wheat (2023) measurements of plant development and yield were conducted. NDVI values differed significantly between MZ in all fields. AGB and clover fractions also differed in two fields, along with the yield of the following crop. One field had significant N-stock differences between MZs before grassland ploughing. This field had more heterogeneity in soil and elevation, which influenced the yield potential (Peralta et al. 2015). This study and the research of Breunig et al. (2020) show the potential of delineation of MZ within the crop rotation based on NDVI maps of cover crops. This can be used for a site-specific fertilization, especially for organic fertilizer as they release the nutrients slower than mineral fertilizer.

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## Fertilizer dependency complements nitrogen use efficiency to improve sustainable management in agrosystems

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### Abstract

Food production requires external nitrogen application to cropping systems; however, we lack metrics to account for society's fertilizer dependency (FDN). Some research shows that 50% of the food produced nowadays is based on the application of synthetic fertilizers, whereas other emphasize that this is a created dependency that could be mitigated by redesigning the food production system. In this work, we propose calculating FDN as the ratio between human-controllable external inputs and total nitrogen inputs. FDN has a solid mathematical base since it is derived from closing the nitrogen use efficiency equation and it has been calculated for cropping systems at various spatial scales based on field, farm (Quemada et al. 2020) and country (Lassaletta et al., 2014) data. At the field experiment, when replacing the barley precedent crop of wheat with a legume FDN accounted for soil legacy and was reduced by 15% in fertilized treatments. In a farm population, FDN ranged from 47% to 95% and accounted for the relevance of biological fixation and irrigation water N inputs. On the country scale, FDN reveals different temporal patterns, depending mainly on the relevance of biological atmospheric nitrogen fixation. Global FDN has risen to ≈83% in the last five decades, even if the nitrogen exchange among regions has increased. FDN has great potential to monitor the reliance of agriculture on external nitrogen sources at different scales and should be reported together with nitrogen use efficiency, surplus and nitrogen output to complement the characterization of resource efficiency, environmental impact and productivity of agricultural systems.

### References

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., Garnier, J., 2014. 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. Environ. Res. Lett. 9 (10):105011-105011. https://doi.org/10.1088/1748-9326/9/10/105011.

Quemada, M., Lassaletta, L., Jensen, L.S., Godinot, O., Brentrup, F., Buckley, C., Foray, S., Hvid, S.K., Oenema, J., Richards, K.G., Oenema, O., 2020. Exploring nitrogen indicators of farm performance among farm types across several European case studies. Agric. Syst.

177:102689. https://doi.org/10.1016/j.agsy.2019.102689

## Nitrogen use efficiency of plasma technology treated digestate compared to untreated, acidified and mineral fertilizer

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### Abstract

The N2 Applied plasma treatment is a method where electrical energy is used to take nitrogen from the atmosphere and use it to enrich liquid organic fertilizers while at the same time reduce pH to limit ammonia and methane emissions. To evaluate the N fertilizer benefits of plasma technology treated digestate, four experiments were conducted in winter wheat in Sweden during the period 2021-2023. Digestate applied from a three-meter wide ramp with 12 outlets equipped with trailing shoes, and mineral fertilizer applied with broadcast application were compared in different treatments in 3m×14m plots replicated in four blocks. Nitrogen offtake was calculated for each treatment by multiplying grain yield with its nitrogen content. From this, nitrogen use efficiency (NUE) was calculated by subtracting the nitrogen offtake in each treatment with that in the unfertilized control and dividing the difference with the mineral nitrogen applied. NUE was similar between N2 Applied treated digestate and digestate acidified with sulfuric acid (on average 48 and 51% respectively).

That was higher than for untreated digestate (37%), but lower than for the granulated mineral fertilizer Axan (64%) which consists of ammonium nitrate. However, for Axan dissolved in water, applied in the same way as the digestate, NUE was similar to N2 Applied treated digestate. A combination of untreated digestate (60 kg N $ha^{-1}$) with a separate application of granulated Axan (70-90 kg $ha^{-1}$) resulted in higher NUE (43% or 50% when acidified) than a single dose (same N amount) of N2 Applied treated digestate (NUE 37%).

## Radish-based cover crop mixtures mitigate N leaching and increase N availability to the cash crop

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### Abstract

Cover crops are grown to capture mineral N in autumn and to provide mineral N in spring. However, these functions can trade-off leading to suboptimal N use. We tested whether cover crop mixtures enhance N capture in autumn without increasing N leaching in spring. In a 4- year field experiment, we rotated cover crops with different cash crops. We used 8 cover crop treatments: monocultures of radish, vetch and oats, all 2- and 3-species mixtures and a fallow. We estimated leaching losses by analysing N concentrations in leached soil pore water and modelling the volume of water leached below the rooting zone. Most N leached in autumn and winter while in spring the amount of N leached was negligible due to water deficit. N leaching in autumn correlated negatively with cover crop biomass, N uptake and root length density. Radish and oats were the most productive species and radish and mixtures that contained radish reduced N leaching by 49–73% compared to fallow. Radish-based cover crops showed quick soil cover, high N uptake and low to moderate C:N ratio. Subsequently, their residues mineralized quickly, resulting in an increase in soil mineral N in spring by 70– 110% as compared to fallow. This mineral N did not leach in spring and was available to the subsequent cash crop. This study demonstrates the importance of species selection in cover crop mixtures and recommends the use of radish-based mixtures if the purpose is to reduce N leaching in autumn and provide mineral N in spring.

### References

Elhakeem, A., Porre, R.J., Hoffland, E., Van Dam, J.C., Drost, S.M., De Deyn, G.B., 2023. Radish-based cover crop mixtures mitigate leaching and increase availability of nitrogen to the cash crop. Field Crops Research 292, 108803. https://doi.org/10.1016/j.fcr.2022.108803.

# Prediction of winter wheat nitrogen status using UAV imagery, weather data, and machine learning

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## Abstract

The critical nitrogen (N) dilution curve (CNDC) and associated N nutrition index (NNI) are known to provide valuable information indicating whether the crops are suffering from N insufficiency. The aim of the current study was to explore the potential of using UAV-based remote sensing together with weather data to quantify NNI in a winter wheat crop. For that purpose, field trials with different N application strategies were conducted over three cropping seasons from 2016 to 2018. The CNDC calibrated in the present study showed a better performance in detecting yield reduction caused by the N insufficiency compared to the curve developed in a previous study (Justes et al., 1994). Machine learning models (i.e., Random Forest and Partial Least Squares Regression) were used to predict shoot dry matter, N concentration, and NNI using UAV-based multispectral images and weather data based on the model developed by Justes et al. (1994) and a newly calibrated model. The NNI predictions based on UAV data and the Justes et al. (1994) model consistently indicated N insufficiency even when the crop was not suffering from N insufficiency. Consequently, will unnecessary N be applied with no yield gain and a possible environmental risk. Recalibration of the CNDC improved the UAV-based prediction of NNI. Robustness and scalability of the CNDC have rarely been discussed but based on our findings we suggest testing if the preferred CNDC should be calibrated for a specific cultivar or region especially when remote sensing technologies are employed for nondestructive N status measurement.

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## Enhancing nitrogen use efficiency in rice and wheat in India

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### Abstract

India is a global hotspot for N surplus. Inefficient N use contributes to massive urea subsidy expenditure (~16 billion USD/year) and ~5% of global anthropogenic GHG emissions linked to N fertilizer use. In India, NUE has declined over the years, 56% in 1961, 39% in 2003, and 35% in 2018 due to injudicious use of nitrogenous fertilizer. Hence, optimization of nitrogen use efficiency (NUE) is imperative for sustaining production. We have evaluated a few technologies such as nano-fertilizers, timely sowing, and site-specific nutrient management practices to improve nitrogen use efficiency in rice and wheat, both crops play a pivotal role in national food security. The results from three years trials (2021-2023) showed that application of nano-urea spray along with 66% of recommended dose of nitrogen (RDN) had higher NUE over 100% RDN without nano-urea in rice and wheat. However, long-term studies are required to see the effect on soil N mining in continuous application of 66% of RDN. In another study we found that timely sowing of wheat (15 Nov to 30$^{th}$ November) had higher NUE than late sowing of wheat (15- 30 Dec). This was mainly due to terminal heat stress during the maturity period in late planted wheat. Data-driven N management is emerging to address the site-specific nutrient management in rice-wheat systems. Through a large-scale survey of production practices and machine learning techniques, we found that 30 Kg N/ha can be reduced from the farmers fertilizers application dose without any yield penalty in Eastern Indo-Gangetic plains.

## Biomass yield and nitrogen use efficiency over nine years in annual and perennial cropping systems

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### Abstract

Emerging biorefinery concepts can lead to new applications and markets for various types of crop biomass (Jørgensen et al., 2022). This may change the cropping systems towards crops with higher yield but also aiming at higher nitrogen (N) use efficiency (NUE). We investigated 7 annual and 7 perennial cropping systems on a sandy loam soil (Manevski et al., 2017), with large variation in N fertilization. Yield of dry matter (DM) and crude protein (CP) as well as NUE for DM yield ($NUE_{DM}$) and CP yield ($NUE_{CP}$) was measured over 9 growth years from 2013 to 2021.

A conventional four-year cash crop rotation, set as reference, achieved mean yields of DM and CP of 10.5 and 0.85 Mg $ha^{-1}$ $y^{-1}$, respectively. An optimized four-year rotation with various annual crops had 51-84% higher DM yield and 42-78% higher CP yield, whereas perennial cropping systems with festulolium and tall fescue had 63-65% higher DM yield and 192-200% higher CP yield.

Compared to the reference system, the optimized rotation had significantly higher $NUE_{DM}$, while festulolium and tall fescue had lower $NUE_{DM}$. However, $NUE_{CP}$ was significantly higher for the grass crops and particularly for the optimized rotation.

Across 12 cropping systems and 9 years, there was a non-linear DM yield response and a linear CP yield response to N fertilization rate. Consequently, $NUE_{DM}$ decreased when increasing the N rate whereas $NUE_{CP}$ remained constant.

In conclusion, novel cropping systems can increase both yield and NUE, and the choice of cropping system and optimal N fertilization may depend on the use of the biomass.

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# Validated simulation of a long-term experiment reveals a pathway to improve productivity and NUE

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## Abstract

Long-term farming system experiments and well-validated dynamic farming system models are a powerful combination to evaluate the production and environmental implications of novel innovations in agriculture. A current deficiency is the lack of comprehensive validations for long-term crop sequences without resetting soil conditions, especially soil mineral nitrogen (Min-N). This reduces confidence in the outcome of scenario analyses for proposed improvements in productivity and sustainability given the central role played by nitrogen dynamics. We used data from a 30-year long-term experiment (Kirkegaard and Lilley 2023) to validate the APSIM model (Holzworth et al. 2014) and achieved excellent predictions for soil and crop responses including the dynamics of Min-N without resetting. A critical step was to ensure that the parameters describing soil organic matter pools matched measurements over the full rooting depth (1.6 m) rather than measured surface layers and default parameters in deeper layers. In scenario analyses of agronomic innovations, including improved N fertiliser strategies, the model predicted potential increases in average annual productivity of 1.2 t/ha (30 %), WUE of 2.0 kg/ha/mm (30%) and NUE of 13 kg/kg (21%) and reductions in N leaching of 8 kgN/ha (-33%) and soil organic matter loss of 3.1 t/ha (31%) (0-10 cm). Our study represents a rare case of model validation capturing the dynamics of soil water, Min-N, biomass and grain yield in a long-term diverse crop sequence to provide confidence in scenario analyses of production and environmental consequences of agronomic innovations.

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## Optimizing nitrogen fertilizer value by post-treatment of digestates

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### Abstract

Anaerobic digestion of animal manures reduces methane emissions during storage while generating energy, benefiting the greenhouse gas footprint. This study presents an innovative digestate treatment approach to enhance the overall nitrogen fertilizer value, increase nitrogen quantity, and diversify digestate-derived fertilizers for different purposes. Cattle manure was co-digested with grass clover silage to augment total nitrogen quantity and biogas yield. The digestates were separated via screw press. The solid fraction underwent drying for storage stability and simultaneously removing ammonia by stripping. A newly designed desulfurizing bio-filter based on liquid digestate as nutrient source for oxidizing bacteria converting sulphide from the biogas to sulfuric acid was used to capture ammonia from the simulated drying of the solid fraction resulting in a sulphur-nitrogen-rich fertilizer product (LiqNS).

The fertilizer value of resulting digestate products and untreated cattle slurry were evaluated in two-year field trials by injection to spring barley. Cattle slurry, anaerobic digestates, liquid digestate, and LiqNS exhibited high nitrogen fertilizer replacement values (NFRV) of 80- 90% relative to mineral nitrogen, with no significant difference amongst them. Liquid digestates showed consistent performance over the years and a higher N/P ratio. Conversely, the dried fibre fraction (DF) demonstrated negative NFRV due to nitrogen immobilization.

However, as a soil amendment in a nitrogen-independent crop like faba bean, DF balanced P and K uptake without yield reduction.

Overall, this novel approach increased fertilizer quantity while maintaining NFRV through co-digestion, offering diverse fertilizer products to meet various agricultural needs. LiqNS emerged as a promising additional fertilizer from biogas production.

## Nitrogen value and environmental impacts by plasma treatment of digestate

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### Abstract

Plasma treatment of slurry and digestate use electricity to fixate nitrogen from air as NOx gasses that turn into HNO3 and HNO2 during injection in liquid digestate. In this way, the content of inorganic nitrogen can be doubled, and at the same time, pH is lowered from around 8.1 to 5.1. The lowered pH reduces NH3 emissions during storage/field application and restricts methanogenic activity. In this study, plasma treatment was applied to the liquid fraction of agricultural digestate to evaluate digestate characteristics during storage and NH3 and greenhouse gases emissions (GHG). Experiments with storage (lab- and full-scale) and field trial studies to determine the fertilization effects were conducted.

In lab-scale, effects of plasma treatment on digestates to a pH range of 4.3-5.4 on pH stability during storage at 10 °C and N availability were examined. The pH was stable when digestate was acidified to pH <5 and the treatments increased N availability by 5-14% compared to the control and inhibit $NH4^{+}$ nitrification. In full-scale storage, the gaseous emissions of untreated digestate (pH = 8.1) and plasma treated (pH = 5.4) were measured in two storage periods. While the treatment proved very efficient at reducing NH3 and CH4 emissions, N2O emissions were increased.

The fertilization effects of the plasma treatment were studied in field trial experiments in wheat (2418 $m^2$ plots fertilized with 100 kg of plant available N). The plasma treatment increased nitrogen use efficiency by 34%. The total impact on improved nitrogen value and GHG emissions will be calculated and presented.

# Trends and Drivers of Nitrogen Use Efficiency on Irish Livestock Farms 2013 - 2021

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## Abstract

Irish livestock systems are characterized by a grass-based production model, where animals spend the majority of the year grazing outdoors. Effective grassland management is therefore fundamental to the success of Irish livestock farming. Central to this is the strategic application of fertilizer, both chemical and organic, to ensure an adequate supply of grass throughout the grazing season and grass silage for the housed period. Nonetheless, excessive use of nitrogen fertilizers poses environmental risks, with high nitrogen surpluses causing potential runoff to watercourses, thereby compromising water quality (O' Mara et al., 2021).

Utilizing data from the Teagasc National Farm Survey (FADN) spanning the years 2013 to 2021, this study looks at the trends in NUE and investigates the drivers of NUE on Irish livestock farms. These drivers include farm and farmer characteristics and well as the adoption of novel practices and technologies. Key innovative strategies examined in this study include the implementation of low emission slurry spreading techniques, the allocation of a higher proportion of slurry spreading activities between January and April, and the manipulation of the nitrate content within feed concentrates (Buckley et al., 2020)

The analysis reveals that these innovative approaches are a significant driver of NUE. Moreover, trends observed over the study period suggest a growing recognition and adoption of innovative practices among Irish farmers, reflecting a broader shift towards sustainable and environmentally conscious agricultural practices. By identifying and promoting effective innovations, this research contributes to the ongoing efforts to enhance the sustainability and resilience of Irish livestock farming systems, ensuring their long-term viability amidst evolving environmental and economic challenges.

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# Deep roots and nitrogen, - catch it, before it is down and out

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## Abstract

Nitrogen leaching loss is the main N loss process in many agricultural systems, and the cause of a range of environmental problems. Even if N fertilization could be matched precisely to crop demand, leaching would still happen, as much of the leaching loss is related to N mineralization in periods with little or no plant growth, leaving the nitrogen prone to leaching loss.

However, unlike many chemical transformation processes which are part of the soil N cycle, N leaching is a gradual rather than a discrete process. N leach down the soil profile, becoming gradually less available for crops, and more prone to final loss to the environment. During this process, the depth of the active root growth and N uptake by crops is critically important for the fate of the nitrogen, determining whether it will be used by the crop or lost to the environment.

Large differences exist among crops in their rooting depth development and final rooting depths. This can be used in different ways to try to reduce N leaching loss. We have studied deep crop root growth, and its ability to increase N recovery. Studied include effects of crop rotation, cover crops, sowing time, and most recently, deep root phenotyping for crop breeding. Studies of root growth have been combined with soil analysis and uptake of deep injected 15N tracer, to study how deep rooting can improve crop nitrogen use efficiency.

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## Nitrogen application and N harvest in major cereal crops in South Asia

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### Abstract

Rice-wheat is the major cereal-based cropping system, grown either in rotation with each other or interspersed with crops like maize, sugarcane, cotton or vegetables, in South Asia, comprising Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka and Maldives. N-fertilizer plays a major role in the agriculture of the region. Compared with the data of 2006, fertilizer inputs have been projected to double by 2050, to make South Asia the highest N input region globally. Amazingly, crop yields do not reflect high levels of fertilizer use, resulting in very low $NUE_{crops}$ values, and N surpluses higher than the 50 kg N $ha^{-1}$ $yr^{-1}$ benchmark (Lassaletta et al., 2014). Concerning wheat and rice, the data indicate that India and Pakistan were overusing fertilizers between 1990 – 2010 (Adalibieke et al., 2023) with high N surpluses and low nitrogen use efficiency ($NUE_{crop}$ at 50% and 25%, respectively). Rice growing in Bangladesh is a rare example of farms with better agro-environmental performance with higher NUE. In Nepal and Bhutan, minimal fertilizer application (mean values of 4 and 8 kg N $ha^{-1}$ $yr^{-1}$, respectively), with low/medium yields resulting $NUE_{crops}$ >90%-100%, suggesting net depletion of soil N reserves. Overall, N-fertilizer application in cereal growing in most South Asian countries, are generally managed as recommendations formulated on the basis of crop response data averaged over large geographic areas. It is necessary to apply N fertilizer reflecting the exact requirement of the crop to increase the NUE and reduce N loss to the environment.

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## Unlocking the legacy: A mechanistic model for assessing nitrogen use efficiency in organic fertilizers over long time-spans

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### Abstract

Assessing the nitrogen (N) use efficiency (NUE) of fertilizers is crucial for optimizing crop productivity while minimizing negative environmental impacts. However, organic fertilizers' long-lasting legacy effect challenges an accurate NUE quantification. A practical tool for fertilizer recommendations, which includes the long-term soil N dynamics post-application, is needed.

We developed a mechanistic model incorporating key soil N processes: mineralization, stabilization and re-mineralization in soil organic matter, and losses (volatilization, leaching). Parameters were defined using literature values. Due to the strong dependency of soil N processes on local pedo-climatic conditions, the model requires calibration with data from local field experiments. Using selected Swiss cropland Long-Term Experiments (LTEs) with organic fertilizers, we computed multiple NUE indicators to assess fertilizer performance over time and sites, highlighting dynamics differences. The resulting NUE were used as an integral part of the NUE model calibration.

Initial N availability (NH4-N fraction) largely determines the long-term NUE for liquid manures (after 10 years, < 2% additional N potentially plant available). The N release from soil organic matter strongly influences long-term NUE for farmyard manure (NUE ranges 30–65% 40 years post-application, depending on model parameters). LTEs exhibit similar increasing NUE trends over time, yet there's a mismatch between the theoretical NUE model and LTEs NUE values, possibly due to changes in fertilization strategies, yield disparities, or overestimation of N2-fixation via temporary ley.

The NUE model facilitates incorporating legacy effects into overall NUE assessment of organic fertilizers. Calibration using LTE data enhances model robustness, aiding implementation in fertilizer recommendations.

## Performance of Urease and Nitrification Inhibitors on N-Use-Efficiency of mineral N-Fertilizers

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### Abstract

Nitrogen (N) is the most important mineral nutrient for cereal production. However, Nitrogen-Use-Efficiency (NUE) of winter wheat worldwide is relatively low with 47%, compared to other cereals, with large differences between countries (Lassaletta et al. 2014). Mainly gaseous N losses of ammonia and nitrous oxide (N2O) from the soil-plant system are responsible for low NUE and pose an economic problem for farmers. Weiske (2006) stated that fertilizers with urease and nitrification inhibitors are one possible solution to avoid or at least reduce gaseous N-losses. But several meta-studies conducted on the matter came to varying results of the efficacy of inhibitor addition. Rose et al. (2018) suggested, that many analyses may underestimate the efficiency because they compare mostly on just one N fertilizer rate and rarely on high yield sites.

This study aims to target those suggestions. In a 3-year field experiment, the performance of inhibitor additions to mineral N fertilizers in comparison to widely used mineral N-fertilizers was conducted on a high yield site (~8.5 t/ha long-term grain yield mean) in northern Germany on 5 different N-intensity levels. Furthermore, the additional costs of inhibited fertilizers were considered to compare their agronomic effectiveness.

First results show a good performance of inhibitor usage. Highest NUE was observed on urea with urease and nitrification inhibitors (+10 % compared to urea). While grain yield at agronomic optimal N intensity was similar between fertilizers grain protein concentration was highest on urea combined with urease inhibitor. The efficacy of urease inhibitor was significantly lower combined with ammonia-nitrate-urea solution compared to urea.

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## The potential of agronomic management to reach required NUEs on croplands at global scale

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### Abstract

Nitrogen (N) fertilizers are needed to sustain crop production, but excess N application have led to widespread exceedance of critical N concentrations in air and water. The type and extent of N-related challenges vary across regions. Spatially explicit targets for NUEs to reconcile crop production with environmental targets have been quantified, but it remains unknown how this improvement can be achieved by agronomic measures. We quantified their impact on NUE at global scale and its potential to meet required NUE increases in view of sustainability and food production targets. We used 2,436 pairs of observations (for maize, wheat and rice) from 407 studies and using 10,936 observations for maize, wheat, rice, and tuber crops, while accounting for soil properties, climatic variables and existing management. The current NUE varied strongly across regions, with a median NUE ranging from 45 to 50% for root and other crops up to 68 to 75% for cereals. The NUE is strongly affected by N dose, crop type, soil texture, phosphorus availability and partly by water availability during the growing season. Measures optimizing the N dose in combination with the best application technology, selection of fertilizer type and timing could substantially increase the NUE. When applied on a global scale the NUE can increase from the current average of 48% to 78%, using optimal combinations of nutrient, crop and soil management. The global mean NUE can increase by 30% allowing most farmers to reconcile crop production with acceptable N losses to the environment.

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# Soil Fertility Management on Nitrogen Use Efficiency and Productivity of Potato in Sri Lanka

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## Abstract

Potato (Solanum tuberosum L.) is intensively cultivated in Sri Lanka, and excess application of fertilizers by farmers are common resulting greater losses to the environment. Thus, effect of different fertilizer treatments namely; Department of Agriculture recommended rate of urea (DOAU), Farmyard manure (FM), Combination of the DOAU and FM, Combination of +25% (more) of DOAU and FM, Combination of -25% (less) of DOAU and FM, Combination of 2nd generation modified fertilizer (Yara) and FM, Combination of 70% DOAU as slow releasing Urea-biochar pellets and FM, Combination of DOAUU and Dicyandiamide (DCD) (7.5 % of N weight) and FM, Combination of DOAU and Cinnamon leaf powder (30% of N weight) and FM, and Combination of -25% DOAU and Biocarbon Hybrid fertilizer and FM on the yield and agronomic Nitrogen Use Efficiency (NUE) of potato was assessed. A field experiment was conducted applying above mentioned treatments at the Seetha Eliya Potato Research Institute using variety granola.

Results showed all DOAU amended nitrogen treatments reported similar tuber yield to the treatment of DOAU. The highest yield was recorded in the treatment of +25% DOAU + FM. The agronomic NUE, was the highest in plants treated with DOAU. The lowest yield was reported in the treatment with Combination of less amount of DOAU (-25%) + Biocarbon Hybrid fertilizer (760kg/ha) and FM. The results revealed that urea amended treatments yielded better and the usage could be reduced by amending with Urea-biochar pellets.

## Advancing Nitrogen Use Efficiency in Agriculture: Field and Controlled Environment Strategies

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### Abstract:

In the quest to mitigate the environmental impact of nitrogen fertilizers while enhancing agricultural productivity, the development of crops with improved nitrogen use efficiency (NUE) has emerged as a critical objective. This synthesis explores innovative approaches to characterizing NUE in crop plants through a dual lens: comparative analysis of plant performance under field conditions versus controlled environments. In the field, the multifaceted interplay between nitrogen acquisition, utilization, and external factors such as soil variability and climatic conditions underscores the complexity of improving NUE. This variability challenges the direct translation of genotypic traits into predictable phenotypic outcomes, highlighting the need for nuanced understanding of plant adaptation strategies and the genetic underpinnings of NUE. Through controlled experiments, we delve into the mechanistic bases of yield reduction under nitrogen stress, elucidating the distinct pathways through which plants manage nitrogen and carbohydrate resources. Our investigation into maize genotypes with contrasting NUE profiles reveals differential regulation of critical yield determinants—kernel set and potential kernel weight—underscoring the potential for targeted breeding strategies that enhance both aspects simultaneously. By integrating field observations with controlled environment data, we propose a comprehensive framework for advancing NUE research. This framework emphasizes the importance of dissecting the genetic and physiological bases of NUE, fostering the development of resilient crop varieties that sustain higher yields with lower nitrogen inputs, thereby addressing the global nitrogen dilemma from both environmental and agricultural perspectives.

## Ammonium supply, an alternative potential to improve the nitrogen use efficiency in oil palm

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### Abstract

Ammonium ($NH4^+$) is an essential nitrogen source for plants, but excessive exposure can trigger stress responses that vary among and within different plant species. This study investigated the phenotypic variations in response to ammonium nutrition in five oil palm genotypes seedlings.

Nitrate nutrition was used as a reference for a non-stressful condition, and three different nitrogen concentrations (5, 10, and 15 mM) were examined. Control groups without external nitrogen application were included for each genotype. Several parameters were analyzed, including plant growth, root length, gas exchange, fluorescence, chlorophyll, reducing sugars, amino acids, proteins, and nitrogen uptake. The results revealed a significant genotype effect, particularly between the interspecific O×G hybrid (a cross between the American oil palm and theAfrican oil palm) and the Elaeis guineensis genotypes. Ammonium nutrition increased shoot growth in all genotypes compared to nitrate nutrition. Additionally, there was a trend towards increased primary root length, amino acids, proteins, and nitrogen uptake under ammonium supply. We observed that ammonium-fed plants exhibited a higher N uptake in the shoot than the root, resulting in more significant biomass accumulation. Furthermore, as the concentration of ammonium increased, there was a corresponding increase in N uptake in the shoot. In contrast, when examining the root, the N uptake under ammonium nutrition varied depending on the genotype, but on average, it was higher compared to nitrate-fed plants.

Despite of the stressful effect of ammonium in plants we did not find differences of this with the nitrate on the physiological parameters evaluated. These findings are promising, particularly considering the recommendation to use ammonium with inhibitors for environmental sustainability of the crop.

## Integration of UAV data and soil-crop modelling for Nitrogen Monitoring

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## Abstract

Nitrogen budget monitoring is an important component of promoting sustainable farming. Minimization of N-losses is an important aspect in adjusting the fertilization and increasing the Nitrogen use efficiency. Depending on the application, the frequency of sampling during monitoring can vary from annual to weekly or daily. Remote sensing techniques offer a solution, enabling the monitoring of vegetation over time and space. We utilize Unmanned Aerial Vehicles (UAVs) for high-frequency data collection together with in-situ data, which is crucial for transforming remote sensing data into crop characteristics and calibrating models. This data can enhance soil process modelling and provide insights into crop characteristics such as biomass and Nitrogen uptake. Process-based modelling and data assimilation can subsequently link the above-ground component with soil functions.

In our research, we have monitored which cover crop (mixture) treatments will perform best in promoting plant N uptake, contributing by nutrient retention during their growth and nutrient return to the soil upon their incorporation. To achieve this, we have used the WOFOST-SWAP model to simulate the varying influence of cover crop monocultures and mixtures on Nitrogen cycling in a 7-year crop rotation on sandy soil. The model estimates the vegetation input into the soil and the nutrient uptake from both cover crops and main crops. Our findings suggest that our integrated approach, combining the model with UAV data and field sensors, can effectively monitor Nitrogen use efficiency. This research contributes to the promotion of sustainable farming practices through effective nitrogen budget monitoring.

## New approaches to address the challenge of low nitrogen use efficiency in agriculture

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### Abstract

The efficiency of nitrogen use from fertilisers applied into agricultural systems remains low despite the large volume of research conducted (Zhang et al. 2015). Concomitant with this are high levels of nitrogen pollution in the atmosphere, land and waters with ecosystem, animal and human health implications. Management (e.g. the Four Rs Nutrient Stewardship framework) and technological approaches (e.g. urease and nitrification inhibitors, coated fertilisers, organic fertilisers) have improved this to some degree but the improvements have been minimal and variable. The lack of progress in this area relates to a number of aspects.

Large variations in the outcomes from using new technologies, such as inhibitors, exists due to the impact of climate and edaphic factors, both of which influence the N loss pathway and its magnitude, and the effectiveness of the technologies (Abalos et al, 2014). In addition, limited commercially viable novel technologies have been developed, and there is poor adoption and uptake rates by the end user due to additional cost of the new technologies, ease of their use, lack of evidence of a guaranteed impact, and the poor understanding by the end user of the impact of low nitrogen use efficiency at the farm level. This paper reports on approaches being taken within the ARC Hub for Innovative Nitrogen Fertilisers and Inhibitors (IH200100023) to improve nitrogen use efficiency in agriculture through a multi-disciplinary approach, and considers how the barriers to adoption can be overcome (Lam et al. 2022).

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# Increasing nitrogen use efficiency in cropping systems – an Australian perspective

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## Abstract

The global aim of halving N waste and achieving a circular nitrogen economy demands attention. Considerable N losses from agricultural soil are a challenge including in Australia where degraded soils and weather extremes often conspire against efficient nitrogen use. Nitrogen losses contribute to the decline of Australia's Great Barrier Reef and the nation's considerable greenhouse gas footprint. We address this challenge by exploring avenues for curbing nitrogen losses by supplementing mineral N fertiliser with organic N, increasing the contribution of biologically fixed N, and exploring custom-made enhanced efficiency N fertiliser. We present how (i) nutrient-rich organic recyclates can effectively supplement mineral N in diverse cropping systems[1,2], (ii) biological N fixation can supplement mineral N fertiliser in sugarcane cropping and support sustainable grazing in Australia's semi-arid rangelands, and (iii) enhanced efficiency fertilisers formulated as biodegradable biopolymer matrix supplies N to pasture[3]. We find that considerable efficiency gains are possible, but that regulators must support farmers to ease the transition towards N efficiency.

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## 1.3 Session 2 - Reducing nitrogen losses

### 1.3.1 Keynote: Laurent Philippot "Bridging microbial community ecology and N-cycling"

Laurent Philippot is a soil microbial ecologist working at the French Institute for Agriculture, Food, and the Environment (INRAE). His main research interest is in bridging microbial community ecology, microbial processes and ecosystem functioning using a trait-centered approach. He has developed this line of research with a focus on microbial guilds involved in nitrogen cycling and greenhouse gas emissions. Laurent Philippot is director of research at the INRAE and also vice head of the Agroecology Department in Dijon.

Bridging microbial community ecology and N-cycling

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Abstract

Microorganisms have a central role in ecosystem processes by driving the Earth's nitrogen cycling. This talk will illustrate how the analysis of microbial communities can help understanding N-cycling in terrestrial environments. Since both denitrification and nitrification are the main processes responsible for the emissions of nitrous oxide, one of the six greenhouse gases considered by the Kyoto protocol, I will focus on the denitrifiers and nitrifiers as model microbial communities. I will discuss the relationships between the composition and abundance of these microbial guilds and N2O emissions. I will also show how drought disturbances can affect these relationships and to what extent management practices in agroecosystems could modulate the response of ammonia-oxidizing communities to drought.

### 1.3.2 Oral presentations

# Exploring Different Typologies of Nitrogen Surplus in Europe towards Reducing Agricultural Nitrogen Pollution

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## Abstract

Intensive agriculture and high livestock density significantly contribute to nitrogen (N) pollution in the European Union (EU), causing negative environmental impacts. Despite many Europe-wide legislations, we still observe high N levels across many water bodies in the EU. The EU recently launched the Farm to Fork strategy (F2F) under the "Green Deal" that aims, among other targets, to halve nutrient losses by 2030 and requires a reduction in fertilizer use of at least 20%[1]. This study focuses on characterizing the spatial-temporal patterns of N surplus and assessing N losses in agriculture using agricultural N surplus as an indicator and using a long-term (1850-2019) annual N soil surface budget across Europe with a 5 arc minutes resolution[2]. Using machine learning algorithm, we identified four distinct N surplus typologies across Europe and examined scenarios to reduce N surplus considering reducing mineral fertilizers and animal manure inputs and adjusting N output considering no change and improved technological and management practices.

Our analysis shows that reducing 20% mineral fertilizer use alone would not be sufficient to halve the N surplus by 2030, and achieves at most a 10-16% reduction. However, specific, realistic scenarios, e.g., ~43% less mineral fertilizer and ~4% less animal manure application, achieve up to 45% N surplus reduction with improved management practices. Overall, our study emphasizes that achieving the F2F goals of reducing N losses will require a comprehensive and region-specific targeted effort to reduce N application in agricultural areas while increasing N use efficiency to maintain sufficient agricultural production.

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# Nutrient amendments dictate N2O production pathways: Role of organic residue, urea, and inhibitors

Késia Silva Lourenço[1,2,3], Bruna Gonçalves de Oliveira[1], Fabiana Cannavan[3], Leandro Carolino Gonzaga[4], João Luís Nunes Carvalho[4], Siu Mui Tsai[3], Eiko Eurya Kuramae[2,5], Heitor Cantarella[1]

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## Abstract

This study investigated the effects of a nitrification inhibitor (NI) on nitrous oxide (N2O) emissions during sugarcane growth in non-till system. Its primary objective was to pinpoint the key N2O producers under organic and inorganic fertilizer applications. Conducted in a tropical region, the field experiments explored the combined effects of liquid organic residue (vinasse), urea, and NI on the abundance of N-cycling microbes. Results revealed that background N2O emissions were primarily generated by nirS-type N2O producers, whereas the application of organic residue alone heightened the activity of heterotrophic denitrifier microbes, encompassing both nirS and nirK genes. Conversely, urea addition increased the presence of ammonia-oxidizing bacteria (AOB) and nirS-type N2O producers, emphasizing the dominance of the nitrification pathway. The introduction of NI reduced AOB abundance, subsequently lowering N2O production rates. When organic residue and urea were jointly applied, N2O production primarily stemmed from AOB and nirK-type N2O producers, with significant increase of N2O-consumers (nosZ). The addition of NI in this mix reduced N2O production rates by nirK-type N2O producers during denitrification due to decreased nitrification rates. The study highlights the influential role of environmental conditions and nutrient amendments on N2O production, with urea favoring nitrification-driven emissions. Interestingly, denitrifiers primarily contribute to background and N2O emissions from organic residue. These findings offer valuable insights for the development of sustainable agriculture no-till production systems, aiming to reduced N2O emissions..

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## Sensing Soil Processes – Chemical Imaging of Ammonia Dynamics and Soil Microenvironments

Theresa Merl[1], Christopher J. Sedlacek[2], Petra Pjevac[2], Lucia Fuchslueger[3], Taru Sandén[4], Heide Spiegel[4], Klaus Koren[1*], Andrew T. Giguere[2*,] Theresa Merl[1], Yihuai Hu[5,8], Johanna Pedersen[5], Silvia E. Zieger[1], Marie Louise Bornø[6], Azeem Tariq[6,7], Sven Gjedde Sommer[5], Klaus Koren[1*, 1] Aarhus University Centre for Water Technology, Department of Biology, Section for Microbiology, [2] Division of Microbial Ecology, Center for Microbiology and Environmental System Science, University of Vienna, [3] Division of Terrestrial Ecology, Center for Microbiology and Environmental System Science, University of Vienna, [4] Department for Soil Health and Plant Nutrition, Austrian Agency for Health and Food Safety (AGES), [5]Department of Plant and Chemical Engineering, Aarhus University, Gustav Wieds Vej 10, 8000 Aarhus C, Denmark, [6] Department of Plant and Environmental Sciences, University of Copenhagen, Thorvaldsensvej 40, 1871 Frederiksberg, Denmark, [7] School of Environmental Sciences, University of Guelph, Ontario N1G2Wq, Canada, [8] Department of Agroecology, Pioneer Centre Land-CRAFT, Aarhus University, Denmark

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### Abstract

Soils are complex biological systems in which biogeochemical processes and changes take place on a small scale but impact the environment on a large scale. The soil microenvironment is impacted by anthropological activities such as agriculture, where nitrogen (N) fertilizers are applied to ensure high crop yields. The extensive use of N fertilizers has led to an increased amount of N compounds lost to the environment through ammonia (NH3) emissions, or leaching of nitrate ($NO3^-$) to waterbodies, among others. To reduce such nitrogen losses, it is important to better understand the dynamics of N species, chemical changes, and microbial activities in response to fertilizer applications on a small scale. Such biogeochemical changes in the soil microenvironment take place with high spatiotemporal heterogeneities, which are difficult to resolve with bulk measurement techniques. Chemical imaging with optical chemical sensors (optodes) for pH, oxygen (O2) and NH3, however, allows to resolve changes of analytes in situ, in real time, with high spatiotemporal resolution and without sample pretreatment (Merl and Koren, 2020). These optodes were applied in laboratory-based studies in non-waterlogged agricultural soils and upon addition of synthetic and organic N fertilizers. This allowed to monitor subsurface NH3 dynamics and associated pH changes in 2D around fertilizer granules, which were further used to conduct chemically informed soil sampling for molecular analyses and nitrification product quantification (Merl et al., 2024). Also, different ways of fertilizer applications were tested while chemical imaging, which showed the differences in NH3 concentrations above soil and influence of soil conditions (Merl et al., 2023). This aids in broadening our understanding of soil processes and NH3 volatilizations.

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## Nitrate leaching from differently managed grass-clover leys in an organic cropping sequence

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### Abstract

After ploughing, the risk for nitrate leaching from grass-clover leys increases depending on time of termination and N demand of the following crop (Hansen and Eriksen, 2016, Kayser et al., 2008). A field trial was established in 2020 near Osnabrück, Germany to investigate the impact of differently managed grass-clover leys on nitrate leaching in an organic cropping sequence of grass-clover – silage maize – winter barley – spring oat. In a randomized block design with four replications, four different grass-clover treatments (mulching vs. harvesting combined with ploughing grass-clover in fall vs. the following spring) were integrated. After fall ploughing of grass-clover stands, winter rye was sown as a cover crop. In the following spring, both – the overwintered grass-clover stand and the cover crop – were terminated and followed by maize. For analysing nitrate concentrations in the leaching water, ceramic suction cups were installed in 80 cm depth below the root zone in each plot and collected bi-weekly during winter. In the three trial years, ploughing mulched grass-clover stands in fall resulted in significantly higher nitrate-N loads (31.8 kg $ha^{-1}$) compared to harvested (25.3 kg $ha^{-1}$) and overwintered stands (10.0/5.4 kg $ha^{-1}$ for mulched/harvested), respectively. After maize, nitrate-N loads were significantly higher when grass-clover was terminated in spring (10.3 kg $ha^{-1}$; mean of two years) compared to termination in the previous fall (6.3 kg $ha^{-1}$; mean of two years) while after the third part of the cropping sequence (winter barley) no effect of the different grass-clover treatments has been observed so far (one trial year).

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## Effects of different N managements on reducing reactive N gases in greenhouse vegetable cultivation

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### Abstract

Reactive nitrogen (Nr) emissions have become a significant concern due to excessive nitrogen (N) application in greenhouse vegetable cultivation, it is imperative to explore appropriate N management strategies that can effectively mitigate Nr pollution. Simultaneous measurements of ammonia (NH3) volatilizations, nitrous oxide (N2O), nitric oxide (NO) and nitrogen dioxide (NO2) emissions are currently insufficient, resulting in ambiguous emissions of Nr gases in greenhouse vegetable cultivation. To address this problem, we conducted a comprehensive experiment in greenhouse vegetable cultivation to investigate the emission characteristics of Nr gas emissions under different managements (increasing the proportion of organic fertilizer, all-organic fertilizer and replacing with controlled-release fertilizer). The results showed controlled-release N with organic fertilizer exhibited optimal reduction of Nr gas loss while maintaining high yield. The emission characteristics showed the duration of NH3 and N2O emission peaks were shorter than NO and NO2. The EFs of NH3, N2O, NO and NO2 were determined, and N2O accounted for the highest proportions among Nr gas emissions. Boosted regression tree model analysis revealed that N application and soil temperature were the main factors influencing NH3, NO and NO2 emissions; soil temperature and fertilizer type were the primary factors influencing N2O emissions. Overall, controlled-release N with organic fertilizer proved to be optimal solution for minimizing Nr gas losses while maintaining high yield in greenhouse vegetable cultivation. This study offered a technical reference to effectively mitigate pollution and carbon emissions in greenhouse vegetable cultivation.

## Nitrogen and phosphorous load reduction approach for catchments to reach water quality targets

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### Abstract

High concentrations of N and/or P are a major impediment to meet good ecological status of many European surface water bodies. Despite decades of efforts to curb nutrient losses, numerous surface waters across Europe continue to grapple with excessive nutrient loads stemming from agricultural practices, wastewater discharge, and various other sources, both point and diffuse. The imperative for load reductions is clear: to stave off eutrophication and restore ecological condition. However, the nature of these loads, the sources of pollution, the hydrological characteristics and connections with upstream water bodies, and the efficacy of mitigation strategies vary significantly from one water body to another.

To determine a set of mitigation measures that will result in good ecological status, policy makers prefer a method in which each sector contributes according to the polluter pays principle. To support this, we have devised a robust methodology for quantifying the nitrogen and phosphorus balance at catchment level of the surface water bodies in a river basin. This approach enables us to pinpoint specific load reduction targets and allocate responsibilities among the sectors responsible for pollution, based on their respective contributions to the overall load within the catchment. Our methodology also factors in the anthropogenic component of diffuse pollution from agriculture, seasonal variations in load, and the intricate routing of pollutants from upstream to downstream catchments within the river basin. To ensure accountability and progress, we collaborate closely with regional water management authorities, such as the Dutch Water Boards, exchanging modeled balances and validating simulated discharge and load data against on-site monitoring within the river basin. By employing this methodology, we can assess multiple modeling scenarios featuring various load reduction measures and gauge their effectiveness in meeting reduction targets across the river basin's catchments.

## Drivers and origins of nitrous oxide emissions in winter wheat

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### Abstract

Nitrous oxide ($N_2O$) is an important greenhouse gas (GHG) and ozone-depleting substance. The agricultural sector is the predominant $N_2O$ anthropogenic source, mainly due to nitrogen (N) fertilizer use, thus policies address N reduction pathways across Europe. However, predicting soil $N_2O$ emissions under field conditions is challenging due to high spatio-temporal variability and limited availability of high-resolution measurements from field experiments.

Thus, we used an eddy covariance measurement station for determining $N_2O$ fluxes at a half- hourly resolution over an entire winter wheat cropping season and a subsequent cover crop in Switzerland. In addition, we monitored meteorological conditions, soil variables, and crop growth, and identified the origin of the emitted $N_2O$ using isotopic signatures.

Our findings emphasize the critical role of management practices (i.e., fertilization and tillage), soil moisture, soil nitrate availability, and crop N uptake in determining peak $N_2O$ emissions. The highest emissions were recorded after the first fertilization event, exceeding 20 nmol $N_2O$ $m^{-2}s^{-1}$. Our results are consistent with Maier et al. (2022) for maize and pea and Feigenwinter et al. (2023) for intensively managed permanent grassland, indicating the importance of plant-microbe N competition in $N_2O$ dynamics. Isotope data suggested denitrification as the dominant $N_2O$-producing process, with nitrification being important only during the first days after fertilization.

These insights into $N_2O$ dynamics in croplands, their sources as well as environmental, biological, and management drivers, provide essential information for informed management decisions to reduce $N_2O$ losses and thus the GHG footprint of crop production.

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## Machine Learning Approaches for Ammonia Volatilization Prediction after Manure Application

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### Abstract

Ammonia emissions pose significant environmental challenges, particularly due to their contribution to fine particulate matter formation. A substantial portion of these emissions arise from ammonia volatilization following field fertilization, resulting in both environmental pollution and nitrogen loss for farmers.

Several models exist for predicting ammonia volatilization from field-applied manure, encompassing process-based, empirical, and semi-empirical approaches. However, machine learning models have not yet been applied to predict ammonia volatilization from field-applied manure. In this study, we show that this new approach can outperform traditional forecasting tools.

More specifically, we compared four machine learning models to a semi-empirical model introduced by Hafner et al (2019) for forecasting ammonia volatilization using the dataset ALFAM2 including emissions collected in more than 1,000 plots in 12 countries (Hafner et al, 2018). From the ALFAM2 dataset, two independent subsets were extracted for training the models and testing their performances. The different models were compared according to standard metrics, commonly used to assess forecasting tools. Our findings reveal that the machine learning models delivered significantly superior performance compared to the semi-empirical model. For instance, the mean absolute error is 33% lower when using the random forest model compared to the semi-empirical model for predicting volatilization dynamics (flux), and 48% lower for predicting cumulative emissions 72 hours after manure application (test dataset). Based on these results, we selected the most accurate machine learning model to explore various scenarios of reduction of ammonia volatilization, relying on different combinations of application methods and manure incorporation techniques. We showed that the outputs of the selected model could be used to identify effective strategies for reducing ammonia volatilization.

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# Temporal patterns of soil $NO3^-$ concentration and leaching differ greatly between 1 m and 2 m depth, according to field measurements and Daisy modelling

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## Abstract

Reducing $NO3^-$ leaching yields is a major challenge in the effort to reduce the environmental and climate impact of agriculture. While there is broad scientific consensus that plant cover during autumn and winter significantly reduces $NO3^-$ leaching in temperate climates, there is still some debate regarding the winter transport and uptake of $NO3^-$ at different depths in the subsoil, and whether existing field data captures a sufficiently complete picture of this. One possible course of action is to take soil $NO3^-$ measurements at greater depths; however, this is not without its own complications. In this study, carried out in the CENTS long-term experiment at Aarhus University, we compared suction cup measurements of soil $NO3^-$ concentration taken at depths of -1 m and -2 m under different plant cover and tillage treatments. We found considerable discrepancies in both the temporal variation of soil $NO3^-$ and the derived yearly $NO3^-$ leaching rates between the two depths, which we conclude undermine the derivation of yearly leaching amounts at -2 m. We support this conclusion with leaching simulations of both $NO3^-$ and conservative tracer using the Daisy agrohydrological model. Finally, we propose that primarily due to dispersion phenomena during long solute transport times, leaching of $NO3^-$ at -2 m must be assessed over several years rather than yearly, and that experimental treatments (e.g., management) must be planned accordingly.

## Can slurry amendments mitigate ammonia emissions during storage?

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### Abstract

Slurry storage can lead to large emissions of ammonia (NH3). Potential of slurry additives to reduce these losses has long been of interest. While slurry acidification is an established NH3 abatement technique, questions remain over many alternative additives.

In this work, a series of incubation experiments was conducted simulating slurry storage under mild, temperate climatic conditions. Treatments consisted of cattle slurry amended with either chemical acidifiers (sulphuric acid, acetic acid, alum, and ferric chloride), waste products and by-products (apple pulp, spent brewers' grain, sugarbeet molasses, dairy washings, grass or maize silage effluents, zeolite, biochar, dairy processing waste, lactogypsum) or commercially available additives. All incubations bar one were carried out using 2 L-capacity experimental units, while one incubation used 20 L-capacity vessels. Experiments used a randomized block design with a minimum of three replicates. Ammonia was measured using a dynamic chamber technique with an INNOVA 1412 photoacoustic gas analyser.

Results showed that slurry acidification proved a reliable method of reducing NH3 in storage under mild winter conditions (5-10°C), with reductions reaching over 90% (Kavanagh et al., 2019). By contrast, other additives showed variable efficacy of mitigation. Waste and by- products that are acidic in nature or lead to acidification through lactic acid fermentation, such as apple pulp, sugarbeet molasses and silage effluents, led to NH3 reductions of between 38% to 67% (Kavanagh et al., 2021). Other by-products and commercial additives showed little or unpredictable and variable impact on NH3 abatement. Potential pollution swapping with greenhouse gas emissions also needs to be considered.

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## Reducing Nonpoint Source Pollution Through Tax Under Climate Change

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### Abstract

A growing body of research suggests that climate change will have an overall negative effect on the challenges of nonpoint source pollution control. Much of this literature has focused on linking projections of changing climate to process-based hydrological and biophysical models, and some simultaneously considered stylized changes in management practices. The role of markets and economic choices, as well as their interaction with the physical world has been left out of the assessment. In this paper, we demonstrate how economic decisions can relate to biophysical properties via the medium of transfer functions. Applying this integrated modeling framework to a hypothetical N loss tax experiment, we find that employing market-mediated instruments to reduce nonpoint source pollution will become more costly due to the still profitable intensification and the increasing opportunity cost of conservation associated with the warming climate. The original tax rate of 1 $/kg of N loss will increase to $1.3 and $1.7 under the RCP4.5 and RCP8.5 emission scenarios to achieve the same amount of N loss reduction. The unit abatement cost will also increase respectively from $10 to $15 and $20 per kg of N loss removal under future climate.

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## Effect of separation and air-plasma technology on $NH_3$ emissions from field applied biogas digestate and pig slurry to grassland

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### Abstract

Different technologies can be utilized to mitigate environmentally harmful ammonia (NH3) emissions after field application of liquid animal manure (slurry). Air-plasma technology can be used as an acidification treatment with the additional benefit of enriching the slurry nutrient value by increasing the amount of inorganic nitrogen. Air is treated in a plasma unit, whereafter the treated air is added to the liquid fraction of slurry after a solid-liquid separation.

The present work investigates the NH3 emissions after field application of the following fractions of pig slurry and slurry digestate: i) untreated slurry (UN), ii) liquid fraction of slurry (LF), iii) liquid fraction of slurry treated with air from the plasma treatment (LP). Emissions were measured with a system of wind tunnels and a cavity ring-down spectrometer for NH3 measurements and a proton-transfer-rection mass-spectrometer for measurements of volatile organic compounds (VOC). For both slurry types, the cumulative NH3 emissions were significantly lower from both LF and LP compared to UN ($P < 0.05$). For pig slurry, there was no significant difference in cumulative NH3 emissions between LF and LP. The slurry separation decreased dry matter by 46-54% and resulted in a rapid decrease in slurry exposed surface area after application, presumably due to high infiltration. Several VOCs were measured after application of the slurry, but continuous emission was undetectable for all VOCs. The very low VOC emission was presumably due to high infiltration of the low dry matter slurry treatments and low concentration of VOC in the digestate.

## Global meta-analysis reveals influence of the type of bacteria in symbiotic nitrogen fixing trees on greenhouse gas emissions

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### Abstract

N-fixing trees are widespread planted in forest and agroforestry ecosystems due to their use for forage and advantages of amending soil quality and carbon sequestration in fragile surroundings. However, it remains unclear if and how N-fixing trees influence $N_2O$, $CO_2$, and $CH_4$ emissions relative to non-fixing trees, a knowledge which is key to mitigating greenhouse gas emissions and slowing global warming. Using a meta-analysis of 276 observations from 55 publications, we showed symbiotic bacterial types of N-fixing trees to be the most important factor influencing and differentiating the magnitude of soil $N_2O$, $CO_2$, and $CH_4$ emissions of N-fixing trees. The actinorhizal N-fixing trees substantially enhanced $N_2O$ emission by 105%. Rhizobial N-fixing trees remarkably increased $CO_2$ and $CH_4$ emission by 11% and 24%, respectively. The amount of N fixed by actinorhizal N-fixing trees seems to exceed their N needs and accelerate $N_2O$ emissions. Higher N demands and N-rich litter of rhizobial N-fixing trees are likely to stimulate microbial decomposition, rhizosphere respiration and inhibit $CH_4$ oxidation by methanotrophs. Despite that these results need to be consolidated by more field experiments to elucidate the mechanisms involved, they suggest that planting of actinorhizal N-fixing trees needs to consider $N_2O$ while rhizobial N-fixing trees should be planted paying attention to reducing $CO_2$ and $CH_4$, emissions.

## Are grooved floor systems a feasible measure to reduce ammonia emissions from dairy barns?

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### Abstract

Dairy farming is a main contributor to ammonia ($NH_3$) emissions. In order to reduce these emissions, several mitigation measures for housing systems are available. However, only few were sufficiently tested under on-farm conditions. The goal of this study was to investigate a flooring system, which is listed by several international guidelines as mitigation measure for $NH_3$ emissions. The investigated system consisted of a rubber flooring with an adjusted scraper. The flooring was equipped with grooves for a quick separation of urine and faeces. The finger scraper was adjusted to the grooves, supposed to clean the floor more effectively and reduce the emission potential from urine.

The system was investigated in the framework of the joint project EmiMin, following the VERA protocol on three naturally ventilated dairy barns in Germany with a case-control-in- time approach. Emissions from the barns were first measured without mitigation measure (control). Then the system was built in, and emissions were measured again (case). After statistical analysis, the mitigation potential of the floor system was derived by comparing the case-emission values with the control-emission values.

The results showed a distinctive site-dependent effect of the measure. For the first location, a significant relative mitigation could be shown. For the second location, no significant changes could be recorded. For the third location, a relative increase of emissions was recorded after implementing the measure. Overall, no significant mitigation effect of the investigated mitigation measure can be concluded.

### Acknowledgement

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## Comparison of seasonal carbon and nitrogen dynamics in winter and spring cereals in Denmark – a simulation study using Daisy

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### Abstract

While much research has been conducted on the potential reduction of autumn and annual nitrogen (N) leaching using cover crops (CC), limited attention has been given to the associated soil buildup and losses of N over extended periods, e.g. multiple crop rotations. The intent of CCs is to take up any excess mineral N after harvest, or N mineralized over autumn and winter, that poses a risk of leaching in the short and long term. This N is subsequently partially released upon termination or senescence of the CC. The temporal dynamics of soil and CC N-turnover are crucial factors for overall N losses.

A constraint of using field trials to quantify these N losses is the physical and economic limitations of the number of variables and combinations that can be tested with sufficient replication for statistical certainty. Furthermore, weather conditions can vary greatly from year to year, complicating the identification of significant explanatory factors.

The use of dynamic simulation models, such as Daisy, allows for the exploration of dynamics for multiple factors, and makes it possible to test scenarios with, among others, varying soils, climates, crop rotations, and fertilizers, and examine the relative effect of such changes.

The aim of this study was to understand the differences in N-leaching and soil-N stock changes between winter and spring cereals, with and without CCs, across diverse soil types and climates. Specifically, we (i) calibrated and validated selected crop models in Daisy on multi-annual, multi-site experimental data, and (ii) performed a scenario analysis with crop rotations with varying proportions of spring- and winter-cereals and CCs.

## Effect of a PGP-based biostimulant application on N2O emissions in a maize crop

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### Abstract

The increasing use of nitrogen fertilizers, driven by global food demand, contributes to rising nitrous oxide (N2O) emissions and declining soil quality. Related to this, one of the challenges of modern agriculture is to find alternatives for the traditional fertilizing sources, such as plant growth promoters-based biostimulants (PGP-BS). PGP-BS are known to enhance soil microbial activity because of their mode of action (Kumar and Verma, 2019). So, there is a potential risk that their application could increase N2O emissions, as they are expected to induce both nitrification and denitrification processes. The aim of this study was to assess the extent to which the application of a PGP-BS could enhance N2O emissions.

An experiment with maize was conducted in Alava (Northern Spain). Ammonium sulphate (180 kg N $ha^{-1}$) was applied as fertilizer. A PGP-BS composed of a Bacillus cocktail was further added together with the fertilizer either alone or together with the nitrification inhibitor dimethylpyrazol phosphate (DMPP), which is a recognized tool for mitigating N2O emissions (Wu et al., 2021). Microbial activity, measured in terms of soil respiration, and N2O emissions were assessed throughout the whole crop lifecycle. The results showed that the application of PGP-BS increased soil microbial activity, leading to an increase in both CO2 and N2O emissions. Alternatively, the application of DMPP led to a 50% reduction in N2O emissions, whether PGP-BS was applied or not. No effect was observed regarding maize crop yield or grain protein content with the application of either PGP-BS or DMPP.

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## Spatial and temporal variability of nitrous oxide fluxes in a German crop rotation

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### Abstract

Nitrous oxide ($N_2O$) fluxes exhibit a high temporal and spatial variability, challenging their accurate quantification. Combining $N_2O$ flux measurements from static chambers and eddy covariance (EC) towers could lead to an improved characterization of the variability of fluxes while providing insights on their underlying drivers.

Since 2022, we monitor $N_2O$ fluxes with an EC-tower in an agricultural field in central Germany. During 2023-2024, we also measure the fluxes with manually-operated static chambers at eight sampling points within the EC-tower footprint. To better understand the spatial variability of the fluxes, we additionally measure 100 points in a 20x20 m grid with a chamber and a portable $N_2O$ analyzer, following fertilization or incorporation of residues after harvest. The crop rotation during the study period was barley - white mustard - sugar beet - winter wheat. To further explore the drivers for $N_2O$ fluxes, mineral nitrogen, dissolved organic carbon and soil water content, were regularly measured in the topsoil.

During the sugar beet cultivation 2023, we observed that soil properties explained the temporal, but not the spatial variability of $N_2O$ fluxes. Measurements of the 100 points exhibited a large variability, with fluxes ranging from -20 to 83 µg $N_2O$-N $m^{-2}$ $h^{-1}$. EC- and chamber-based $N_2O$ fluxes were comparable, but some of the emission peaks captured by the EC-tower were missed with the chambers. EC-based $N_2O$ fluxes were highest after rainfall events in late June 2023 and this 10-day-period accounted for ~50% of the annual $N_2O$ budget. In contrast, post- fertilization emissions were negligible for the annual budget.

## Understanding the fate of N species in the agricultural systems

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### Abstract

Nitrogen is an essential element and a valuable resource that supports life on Earth. However, the cycling of N within agricultural systems are not conservative enough so that large amount of N is leaked into the environment unintentionally, which results in serious environmental problems. We developed a new dynamical, process-based emission model AMmonia-CLIMate (AMCLIM) to quantify agricultural ammonia ($NH_3$) emissions. The AMCLIM model includes important physical, chemical and biological processes and incorporates the effects of both environmental conditions and local management practices. AMCLIM also simulates other N pathways, such as crop N uptake, nitrification, runoff, leaching and diffusion. In 2010, approx. 102 Tg N was from use of chemical fertilizer, and 99 Tg N was excreted from livestock. Overall, 22 % of total N was lost through $NH_3$ emission from housing, manure management, and land application of fertilizer and manure. High temperature and dry conditions are found to facilitate $NH_3$ volatilization, and other factors including soil pH and wind speed can be crucial. Around 50 % of N is taken up by crops or entered soils, while the remaining N underwent various processes and was lost through runoff (2 %), nitrification (9 %), leaching and diffusion (13 %), and a small amount of N from livestock excreta was lost because of poor management (3 %). Focusing on $NH_3$ mitigation, simple and easy measures can be effective, like fertilizer deep placement, manure coverage, etc. A 40 % of reduction in global $NH_3$ emissions are possible if combine a suite of tested methods.

## Significant reduction of ammonia, methane, and nitrous oxide emissions through covering of stockpiled broiler litter

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### Abstract

Ammonia, nitrous oxide, and methane are gases emitted from agricultural activities that are harmful to the local environment and climate.

Solid animal manure is frequently stored in stockpiles until being applied to agricultural field. It has been found that it is possible to reduce ammonia emissions for cattle deep litter with certain management practices (Pardo et al., 2015; Lemes et al., 2023).

The backward Lagrangian stochastic (bLS) method was used to measure emissions of ammonia, methane, and nitrous oxide from a stockpile with broiler deep litter in 30 minutes intervals using cavity ring-down spectroscopy analyzers. The stockpile was farm-scale size and was built directly after the broiler house was cleaned. Temperature sensors were placed inside the pile to monitor temperature changes.

The stockpile was uncovered for the first 6 days before being covered with plastic tarp for 26 days. The plastic cover was removed, and the pile was left uncovered for 10 days at the end of the experiment.

During the covered period the emissions were significantly lower than during the uncovered periods for all three gases: ammonia (92-95%), nitrous oxide (82-89%), and methane (25-40%). With a substantial contribution from nitrous oxide, the GHG emissions in CO2-eq. were 63-72% lower during the covered period. This indicates that covering reduces access to oxygen and thereby limits the production of nitrous oxide through coupled nitrification-denitrification processes.

These results provide clear evidence that immediately covering broiler deep litter can reduce agricultural gas emissions.

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## Liming halved N2O emissions following plowing of grass-clover mixtures in an acidic soil

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### Abstract

#### Introduction

Leguminous in ley mixtures and green cover crops in rotation with cash crops are means to increase nitrogen use efficiency and/or reduce N losses.  However, their benefits can be offset by increased N2O emissions following termination by tillage. Liming of low pH soils can reduce N2O from denitrification[1)], but the effect on total N2O emissions from incorporation of nitrogen rich green residues[1)] is uncertain, as it can also enhance mineralization and nitrification.

#### Methods

We measured field N2O emissions following ploughing of several ley mixtures. Treatments were repeated in control (pHaq  ~5.5) and limed (pHaq  ~6.0) plots which were wholly randomized in a silty clay loam at Ås, Norway. Liming took place shortly before establishing the leys, 4 years before ploughing.

#### Results

N2O emissions increased with increasing ley yields in the previous years, which indicates a linear relationship with residue amounts.  However, at any level of previous biomass yield, N2O emissions in limed treatments were only half of those in low pH treatments. In this experiment the biomass yield dependent on species composition and N fertilization, not on soil pH, and was higher in red clover-grass than in grass only or white clover-grass mixtures. Liming significantly raised the total mineral N content in the soil, but the increase was small (typically around 3 mg N $kg^{-1}$).

#### Conclusion

Maintaining a sub-neutral pH can effectively mitigate N2O emissions following incorporation of nitrogen rich green residue. Whether this applies also in the case of large incorporation of fresh herbage deserves further studies.

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## Nitrous oxide emission reduction by inhibitors: A DNDC model simulation for a cold temperate climate

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### Abstract

Application of nitrification and urease inhibitors (NUI) is an effective $N_2O$ mitigation strategy and does not impact crop yields negatively and sometimes they even have a positive effect. However, it is not clear under which climate and soil conditions inhibitors are most effective and their impact over both growing and non-growing season. Here we are investigating the ability of the DNDC model to simulate the observed reductions in $N_2O$ emission when NUI is applied under contrasting soil and climate conditions. We evaluated the Denitrification-DeComposition (DNDC) model by calibrating and validating the model with high frequency continuous field measurements over 3-years of soil (temperature, moisture, mineral N), crop (yield, N uptake) and $N_2O$ emissions measured using a micrometeorological high-resolution method for Ontario, Canada. The high temporal resolution data was collected in Elora, Ontario in an experiment that included management of four 4-ha farm-scale fields with conventional sources of N (urea or urea-ammonium-nitrate, UAN) with (+) and without (–) NUI, and two methods/time of application (urea broadcasted at planting and UAN injected at 6-leaf- stage). The model was improved by incorporating the preferential water flow mechanism. The results showed that DNDC provided fair to good estimation of soil temperature, moisture, crop yield, and daily $N_2O$ fluxes. The measured reduction of annual $N_2O$ emissions for Urea+NUI and UAN+NUI, compared to Urea–NUI and UAN–NUI was 15 % and 25 %, respectively. DNDC slightly overestimated for Urea (25%) but predicted similar reduction in $N_2O$ emissions when applying NUI to UAN (16 – 29 %).

## Drivers of nitrogen cycling in managed wetland soils

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### Abstract

Riparian wetlands in Western and Northern Europe have endured centuries of artificial drainage, altering their natural nitrogen (N) cycling dynamics. This drainage facilitates soil aeration, enhancing N mineralization and increasing N availability. Beside of this internal loading, these wetlands, originally crucial as buffer zones for diffuse agricultural pollution, now experience elevated external N inputs from both agricultural upland and atmospheric deposition of ammonia and nitrate. This shift from a nutrient-deficient to an N-excessive system leads to heightened hydrological export and gaseous N losses, alongside increased microbial N assimilation. Eutrophication resulting from these anthropogenic disturbances significantly impairs the biodiversity and ecosystem functioning of the wetland and downstream systems. However, there is growing public awareness regarding the conservation and restoration of anthropogenically altered wetlands (Hoffmann et al. 2020). Current restoration efforts primarily focus on re-establishing water-logged conditions to improve water quality by mitigating diffuse pollution from fertilizer application. While denitrification can alleviate most nitrate pollution, increased export of reduced nitrogen forms such as ammonia and dissolved organic nitrogen may offset this effect. The impact of various determinant factors—such as temperature, soil quality, and nitrate loading rate—on the role of rewetted wetlands as N sinks or sources over inter-seasonal temporal scales remains uncertain. Nonetheless, numerous laboratory studies under diverse conditions have advanced our understanding of factors controlling N cycling in wetland soils (e.g. Cabezas et al. 2012, Walton et al. 2020), offering valuable insights for managing N pollution in freshwater and marine systems.

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Urine Nitrogen Concentration influences Ammonia Emissions following Urine Deposition

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## Abstract

Ammonia (NH3) emissions from urine nitrogen (UN) deposition by grazing livestock negatively impact air, water, and soil quality. Dairy cow UN concentrations vary significantly (2 – 20g N/l), yet comprehensive studies on the correlation between UN concentration and NH3 emission in grazed grasslands are lacking. Understanding this relationship is vital for effective nitrogen management and improved modelling capabilities. Therefore, we conducted a study in a temperate loamy-luvic-gleysol dominated by perennial ryegrass (Lolium perenne). Urine nitrogen concentrations were controlled by diluting or spiking urine from Holstein-Friesian dairy cows (7.1 g N/l), formulating concentrations of 0, 2.5, 5.0, 7.5, and 10.0g N/l. Urine patches were simulated in April and July 2023 by uniformly applying 2L to a $0.16m^2$ area within each $2.25m^2$ plot, employing a randomised complete block design. Ammonia emissions were monitored daily for 14 days post-application using an INNOVA 1412i analyser. Ammonia emissions significantly increased (>100%) with rising UN concentrations in both April and July, ranging from $0.3g\ N/m^2$ to $6.6g\ N/m^2$ across the 0g N/l to 10.0g N/l treatments. Unexpectedly, mean NH3 emissions in April ($3.5g\ N/m^2$) significantly exceeded July ($1.1g\ N/m^2$), possibly due to higher soil moisture in April and extreme drought conditions in July pre-application. These results indicate that lowering UN concentrations through diet manipulation may be a potential strategy to reduce NH3 emissions from pasture. They also suggest that actual meteorological and soil conditions may better predict NH3 emission risk than the calendar time-of-year, emphasizing the need to prioritize these factors in modelling.

## Acknowledgement

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## Quantifying N2O fluxes in a managed grassland following the application of contrasting fertilisers

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### Abstract

Nitrogen fertiliser application represents the largest contributor to nitrous oxide (N2O) emissions from agroecosystems, with the magnitude of these emissions dependent on the types of fertiliser used. Though different straight nitrogen and (nitrogen, phosphorus, potassium) NPK compound fertilisers are used in soils, there is still a lack of information regarding the fertiliser composition effects on N2O emissions. This study investigates the effects of fertilisers with differing nitrate-to-ammonium ratios (100-0%) on N2O emission. Fertiliser formulations; calcium nitrate (CN), NPK 27-2.5-5, NPK 18-6-12 and ammonium sulphate (AS) were applied at a rate of 200 kg $ha^{-1}$ $yr^{-1}$ in 5 equal splits to a managed grassland. Nitrous oxide fluxes were measured for a year using an automated flux system. Fluxes ranged from -2.07 to 271.34 g N2O-N $ha^{-1}$ $d^{-1}$. Cumulative fluxes from AS, NPK 18-6-12 and NPK 27-2.5-5 were significantly reduced by 83%, 61% and 30% respectively compared to CN under wet soil conditions (>0.45 $m^3$ $m^{-3}$) in the first application. However, under drier soil conditions (<0.30 $m^3$ $m^{-3}$) in the second and third applications, there was no significant effect of fertiliser type on cumulative emissions. With soil moisture exceeding 0.35 $m^3$ $m^{-3}$, cumulative emissions were significantly reduced from AS (67%), NPK 27-2.5-5 (52%) and NPK 18-6-12 (40%) compared to CN in the fourth application. In contrast, cumulative emissions were significantly reduced from NPK 27- 2.5-5 (60%), CN (51%) and NPK 18-6-12 (33%) compared to AS. The N application timing and type of fertiliser formulation can have a profound effect on N2O losses.

### Acknowledgements

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## Mitigating N2O emissions from an intensive coffee production system in northern Zambia

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### Abstract

Around 70% of the carbon footprint of end-products such as coffee and chocolate is associated with greenhouse gas (GHG) emissions during the primary production of agricultural ingredients. Options for lowering the carbon footprint of these products are limited, as few empirical data are available from these systems. To benchmark current GHG emissions, particular attention must be paid to the use of nitrogen fertilizer because of the associated nitrous oxide (N2O) emissions. A series of field and incubation experiments are ongoing on an intensively managed coffee farm in northern Zambia, aiming to benchmark N2O emissions from current management practices and to underpin effective mitigation strategies. These experiments focus on the effect of fertilizer source, rate, and application technique, as well as the use of nitrification inhibitors and organic residues. Results from the first growing season indicate that emission factors (EFs) are higher for calcium ammonium nitrate (CAN) than for urea, and that EFs can be lowered by adjusting the rate to crop demand. The addition of nitrification inhibitors appears to be an effective mitigation strategy and reduces cumulative emissions from urea by ~40%. The addition of composted residues amplified N2O emissions from CAN, but no significant interaction was found between urea and compost. Emissions in the canopy drip line were characterized with short peaks after fertilization, whereas emissions near the tree stem were high throughout the growing season, stressing the importance of considering within-field heterogeneity. Experiments will be continued into 2025 and EFs will be established based on a 2-year measurement period.

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## Trends of nitrate concentration and transport in agricultural headwater streams in Denmark

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### Abstract

Denmark as one of the most intensively farmed countries in the world has enforced mandatory regulations on agricultural production since the late 1980s. Based on the study by Petersen et al. (2021) we demonstrate the outcome of the regulations imposed on agriculture by analysing decadal trends in nitrate ($NO_3^-$) concentrations and loads in streams using 30-33 years of detailed monitoring data and survey of field level information on agricultural practices from six intensively cultivated headwater catchments.
We divided the annual data into four subperiods defined by the time of introduction of different mitigation measures: i) 1990-1998, ii) 1999-2007, iii) 2008-2015, and iv) 2016-2022. By analysing the changes in $NO_3^-$ load-runoff (L-Q) relationships between the four sub-periods combined with Mann-Kendall correlation analyses we investigated the influence of four groups of drivers on stream $NO_3^-$ transport: Climate, land use, agricultural practices, and biogeophysical properties of the catchments.

Correlation analyses of annual flow-weighted stream $NO_3^-$ concentrations and/or loads revealed significant relationships with factors representing all of the four groups of drivers including factors such as precipitation, large scale climate fluctuations, runoff, previous year's runoff, baseflow index, number of annual frost days, agricultural area, livestock density, field N surplus, catch crop cover, manure storage capacity, method and time of manure spreading, and time of soil tillage.

Shifts in L-Q relationships between sub-periods demonstrated the effect of changed agricultural practices. Our analysis shows a unique example of how agriculture can change its environmental impact, and how the effect of various measures differs between catchment types.

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Managing crop residue to reduce the N losses of crop production in the US Corn Belt

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## Abstract

Historically, crop residue retention was important to maintain soil organic matter and reduce erosion. However, crop residue inputs in the US Corn Belt have reached unprecedented high levels. Furthermore, this region is characterized by high soil organic carbon contents and moderately to poorly drained soils, so excess water frequently limits crop production and stimulate N losses as $NO3^-$ leaching and N2O emissions (Lawrence et al., 2021). In this study we hypothesize that removing a fraction of the crop residue in corn and soybean systems that does not compromise the soil organic carbon stock in the US Corn Belt can lead to a reduction in the N losses as $NO3^-$ leaching and N2O. The reduction in the N losses can be promoted directly by reducing the fertilizer rate and indirectly by reducing soil moisture. To test this hypothesis, we performed a systematic review of published data based on field experiments in the US Corn Belt and a simulation analysis using APSIM model. Our results indicate that residue removal reduced the agronomic optimum N rate in corn by 22% (47 kg N $ha^{-1}$). Moreover, a 66% residue harvest increased grain yield by 6% compared to the 0% residue removal scenario while there was an 81% reduction in $NO3^-$ leaching (17 kg N $ha^{-1}$), and 20% reduction in N2O emissions (1.4 kg N $ha^{-1}$). We suggest that there is an immediate opportunity for farmers in the region to reduce the N losses by removing part of the crop residues.

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## Assessing the Impact of Cover Crops on N2O Emissions: Results from a Two- Year Field Trial with Hairy Vetch and Oilseed Radish.

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### Abstract

Cover crops are effective in decreasing nitrate leaching from cropping systems, but their impact on nitrous oxide (N2O) emissions is not fully understood. While cover crops deplete soil mineral nitrogen (N) during growth, they may also reduce N2O emissions. However, after termination or death, emissions may increase due to input of labile carbon and mineralization of plant residue N. This study aimed to quantify the net effect of cover crops on N2O emissions over the full cropping cycle. We conducted a two-year field trial on a sandy soil in Denmark with hairy vetch and oilseed radish as cover crops, grown at two residual N levels. N2O fluxes were measured weekly throughout the year using the closed chamber method. In both years, cover crops caused a slight reduction in N2O emissions in autumn, but this decrease was offset by higher emissions during winter and spring. The radish died during the frost period, which combined with high soil moisture levels resulted in high N2O peaks upon thawing, while the vetch primarily increased emissions after soil incorporation in the spring. This resulted in annual net positive cumulative N2O emissions from cover crops, particularly from radish during the second year. The results indicate that the potential of radish to reduce N2O emissions may be compromised by its limited winter hardiness and rapid biomass degradation, as these factors may contribute to increased N2O formation during frosty winters. However, the reduced nitrate leaching from cover crops also reduces N2O emissions from surface waters receiving drainage and runoff from the crop fields (indirect N2O emissions). This should be considered when evaluating the overall environmental effect of cover crops.

Cover crops and soil tillage differently affect N2O emissions.

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## Abstract

Cover crops can affect nitrous oxide emissions (N2O) when incorporated as residues into the soil, however, this may differ depending on tillage strategy and cover crop. The objective of this case study was to quantify N2O emissions as influenced by these factors. Perennial ryegrass (RG, Lolium perenne), plantain (PL, Plantago lanceolata), RG-PL, and RG-PL-red clover mix (RG-PL-RC, Trifolium pratense) with 82, 103, 55, and 136 kg biomass N/ha were either terminated by shallow rotovation followed by deeper ploughing (ro+plou), or directly by ploughing (plou), respectively. The N2O flux was continuously measured with automated chambers from March – June 2021 (DOY 72-166). Measurements were not replicated, but plot variance was evaluated. Cumulative N2O-N emissions were higher for plou (3.7-7.5 kg/ha) than for ro+plou (1.2-3.7 kg/ha), with 2-to-5-fold higher emissions in plou for RG-PL, RG, and PL, and the smallest difference in RG-PL-RC. In ro+plou, lowest and highest cumulative N2O emissions were in PL and RG-PL, while in plou it was RG-PL-RC and RG- PL, respectively. Average soil NO3-N accumulated from 3.5 to 10.4 and 2.9 to 8.6 mg/kg in ro+plou and plou, respectively (DOY 84-119), indicating mineralization and nitrification of residue-N. Thereafter, NO3-N gradually decreased and N2O emissions increased, indicating denitrification as the main process of N2O production. The results demonstrate possible interactive effects of cover crop and tillage on N2O emissions, and that ro+plou consistently reduced N2O emissions under the studied climatic and soil conditions. This case study contributes further on how cover crop type and tillage strategy affect N2O emissions.

# $N_2$ and $N_2O$ fluxes and processes depending on biogas digestate application technique - a soil incubation study

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## Abstract

Soil denitrification is known to be affected by the application technique of liquid manures, such as cattle slurry or biogas digestates due to the supply of nitrogen and reductants and to oxygen ($O_2$) consumption by decomposition. The formation of anoxic microsites where denitrification can occur thus depends on quality and spatial distribution of incorporated manures in interaction with physical and chemical soil properties. Until now, dinitrogen ($N_2$) and nitrous oxide ($N_2O$) fluxes related to slurry incorporation patterns have been rarely studied and are poorly represented by current models.

In a field study we compared digestate-induced $N_2O$ fluxes in conventional and no-till treatments with incorporation by ploughing or below-root injection of biogas digestate in maize, finding that highest fluxes occurred in no-till, whereas below-root injection did not lead to enhanced $N_2O$ flux (Well et al. 2024). Here, we present results from a lab study to further elucidate $N_2O$ processes induced by the application mode. We compared surface application with and without incorporation and by below- root application. We used $^{15}N$-labelling of intact soil cores of an arable silt-loam soil to quantify $N_2O$ reduction to $N_2$ and for source partitioning of $N_2O$ fluxes (Kemmann et al. 2021). In parallel, natural abundance isotopic values of $N_2O$ fluxes from non-labelled replicates were used to further specify processes (Lewicka-Szczebak et al. 2020). Results show that slurry application techniques affect the magnitude and temporal dynamics of total denitrification fluxes, the product ratio of denitrification and the fraction of the $N_2O$ flux originating from the labelled $^{15}N$ pool.

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# Evaluating the potential of easily degradable soil additives for reducing post-harvest nitrogen loss

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## Abstract

One of the most pressing issues in intensive agriculture is how we can reduce post-harvest losses of nitrogen (N) on agricultural land. Here, we present results from laboratory incubations and field trials with different soils under a range of conditions based on the stimulation of microbial biomass growth by readily available organic soil amendments. They show that effective immobilization of mineral N in large quantities (up to 100 % reduction of nitrate concentration in the soil) is possible for several months, even under winter conditions. A consistent picture emerges from the results, suggesting that the optimal and longest-lasting effect of N immobilization can be achieved with nitrogen-free organic compounds that are moderately available to microorganisms (i.e., within several weeks rather than a few days). If the microorganisms are offered compounds that are too readily available (extreme case: glucose), a rapid stimulating effect can be triggered, which, however, does not last long enough to immobilize N for several months due to too early remineralization. If too recalcitrant organic compounds are introduced into the soil, the utilization of the additional carbon source takes too long to lead to effective N immobilization. We have taken a significant step forward in understanding the mechanisms and timing of microbial N immobilization and remobilization, which may prove key to solving the N surplus problem in agriculture. However, the extent to which such management measures can be implemented in agricultural practice also depends on the political framework conditions that make them economically feasible.

## Measuring denitrification using innovative techniques

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### Abstract

Soil emissions of nitrous oxide ($N_2O$) and dinitrogen ($N_2$) reduce fertilizer N use efficiency. While $N_2O$ flux measurements are common, quantifying $N_2$ losses is challenging due to atmospheric background. This study presents recent advancements for both state-of-the-art techniques to directly measure $N_2$ emissions - the $^{15}N$ gas flux ($^{15}NGF$) method and the Helium soil core technique (HSCT).

The $^{15}NGF$ method hitherto lacked independent verification, leaving uncertainty about potential measurement bias. We quantified $N_2$ emissions from a wheat rotation using the $^{15}NGF$ method and compared them with corresponding results from a lysimeter-based $^{15}N$ mass balance approach. $N_2$ emissions ($^{15}NGF$) were similar to estimates obtained from the mass balance approach for four different sampling periods, thereby confirming the accuracy of the $^{15}NGF$ technique under field conditions.

The HSCT has primarily been limited to dark incubations, neglecting the potential influence of active plants. Therefore, we developed and tested a novel large plant-soil mesocosm incubation system for measuring $N_2$ and $N_2O$ in a light-accessible $N_2$-free atmosphere. In a 33- day incubation with wheat plants, significantly higher $N_2$+$N_2O$ losses were observed in sown soil (0.34±0.02 gr N $m^{-2}$) as compared to bare soil (0.23±0.01 gr N $m^{-2}$). $N_2$ fluxes accounted for approximately 94-96% of $N_2$ + $N_2O$ gaseous N losses in both planted and unplanted mesocosms. This highlighted the dominant role of $N_2$ for total denitrification losses also in nitrate-rich agricultural systems and the overall stimulating role of plants for soil denitrification.

## Efficiency of the nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP) to reduce nitrification and $N_2O$ emissions following application of various organic fertilizers.

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### Abstract

Minimizing nitrogen (N) losses represents a significant challenge for agriculture. One mitigation strategy is the use of nitrification inhibitors (NIs), slowing down the conversion of ammonium ($NH4^+$) into nitrates ($NO3^-$) and thus reducing $NO3^-$ leaching and nitrous oxide (N2O) emissions induced by N fertilization. The aim of this study was to assess the efficiency of a synthetic NI, the DMPP, in reducing nitrification and N2O emissions following the application of different fertilizers. A short-term soil incubation experiment was established under conditions favoring nitrification. Nitrogen source was applied either as mineral fertilizer (ammonium sulfate AS) or as organic residues (plant-based digestate D, orgamine O7, chicken manure CM, cattle slurry CS) at a rate of 100 mg N $kg^{-1}$ dry soil, with/without DMPP. After fertilization, N2O emissions, mineral N and nitrification genes abundance were assessed. A follow-up incubation experiment (same conditions, same analyses) was set up to compare the efficiency of rhizospheric soils from white mustard genotypes with suspected BNI property, to DMPP's efficiency. Three fertilizers (AS, D and O7) were applied on each soil type. For the main experiment, we observed that DMPP was more efficient with fertilizers AS and D which were both associated with the highest ammoniacal N and N2O emissions. However, DMPP was much less efficient with animal-based fertilizers CM and CS since these fertilizers may have promoted denitrification over nitrification. The additional experiment highlighted the potential of white mustard rhizopheric soils to reduce N2O emissions and that their efficiency was fertilizer type dependent.

# Nitrogen release from cover crops

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## Abstract

The legacy effect of cover crops on subsequent cash crops in the rotation remains unclear. Of particular relevance is the timing of nitrogen release from cover crop residues and how this influences the nitrogen fertiliser requirement of the following cash crop and subsequent nitrate leaching losses. Furthermore, given the uncertainty over the future of glyphosate, more information is required to help farmers develop alternative destruction methods that do not compromise establishment and management of the following cash crops.

The project quantified the impact of two contrasting cover crop mixes and destruction methods on over winter nitrate leaching, soil nitrogen supply and the performance of the following two cash crops in the rotation. Cover crops and a weedy stubble control were established at two experimental sites and destroyed using either glyphosate or a mechanical method (chop and incorporate or rolling on a frost).

Overwinter nitrate leaching losses were reduced by up to 90% under the cover crop treatments, which also increased spring soil nitrogen supply by up to c.35 kg N/ha. Following destruction, spring topsoil mineral nitrogen levels were higher where covers had been destroyed using glyphosate. Spring cereal yield, grain nitrogen offtake and total crop nitrogen uptake were consistently reduced where the covers had been destroyed mechanically than by using glyphosate. There was no legacy effect of cover type or destruction technique on either the nitrate leaching losses measured over winter following spring cereal harvest or on the subsequent spring soil nitrogen supply.

## Using ARMOSA model for assessing the effect of two cropping systems on regional N2O soil emissions

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### Abstract

The main greenhouse gases (GHG) emitted from non-flooded agricultural soils are carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$). GHG emissions assessment assumes increasing relevance in the evaluation of alternative soil and crop management practices mitigation potential (Chataut et al., 2023), as influenced by pedoclimatic conditions. $CO_2$ and $N_2O$ soil fluxes were measured in continuous (with eight flow-through non-steady-state automatic chambers) for four years in a pilot farm located in northern Italy (Ravenna) for two cropping systems, conventional (CCS) and efficient (ECS), thus allowing the calibration and validation of ARMOSA simulation model (Perego et al., 2013, Gabbrielli et al. 2023). The two compared cropping systems employed the following crop rotation: maize, durum wheat, processing tomato, durum wheat (CCS); pea, durum wheat + alfalfa, processing tomato, durum wheat + alfalfa (ECS).

A regional up-scaling was then performed by running the validated model on the region's Agri4Cast 25 km grid, for soil texture (7 soil classes) and soil organic carbon (3 soil classes) from 1979 to 2022, simulating the two cropping systems. In total 4,320 simulations were runned, following a soil class×Agri4Cast cell×cropping system factorial design, while the study area covers 16,875 $km^2$. For equal soil class, simulated results showed lower $N_2O$ emissions (0-10 cm depth) in ECS cropping system (0.3-0.95 kg N-$N_2O$ $ha^{-1}$ $year^{-1}$), and confirmed a downward emissions trends for increasing sand content. From the application of a random forest algorithm, it emerged that $N_2O$ deriving from denitrification was mainly influenced by soil texture, while the most relevant effect on $N_2O$ deriving from nitrification was induced by soil organic carbon and its mineralization.

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# Detecting Field-level Cover Crop Growth and Tillage Intensity in the EU Using Multi-source Satellite Data and Process-guided Machine Learning

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## Abstract

Cover crops and conservation tillage are two major practices for reducing cropland nutrient leaching between main cropping seasons. Accurate information of field-level cover crop growth and crop residue cover at the regional scale is important for assessing conservation program implementation (Zhou et al., 2022) and supporting agroecosystem modeling of cropland biogeochemical processes (Ye et al., 2023). Remote sensing can detect cover crop growth and crop residue cover cost-effectively, yet existing regional-scale studies in Europe are rare. To fill this data gap, our study developed explainable machine learning algorithms that integrate multi-source satellite data (e.g., Sentinel-2, Sentinel-1, and SMAP) to quantify cover crop growth and crop residue cover. Specifically, we used radiative transfer process- guided machine learning (PGML, Wang et al., 2023) to quantify the spatial and temporal variability of cover crop aboveground biomass and nitrogen content across Denmark. For crop residue cover, we developed a data engine to derive the ground truth from field photos. Then, we utilized satellite time series data of spectral tillage indices, soil background reflectance, soil moisture, and SAR backscattering to detect crop residue cover. Results show that PGML achieved high accuracy in quantifying cover crop aboveground biomass ($R^2$ = 0.65, relative RMSE =17.4%) and nitrogen content ($R^2$ = 0.63, relative RMSE =23.1%). The synergy of optical and SAR data provides high accuracy in detecting crop residue cover across the EU ($R^2$= 0.71, relative RMSE =21.3%). These remote sensing-derived datasets on agricultural management practices can support field-level nutrient management to ensure agroecosystem productivity and sustainability.

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# AgrosceNa-Up: nesting system and spatial scales in the long-term to improve N management

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## Abstract

The project Agroscena-Up represents a detailed and complete description of the agricultural and agri-food system from the perspective of nitrogen (N) flows. An analysis of the evolution of N flows has been carried out, considering the long-term (1860-1990 period), another more recent period (1990-2015). The integration and interaction of N budgets at multiple scales has been analyzed, using various complementary indicators adapted to the Mediterranean climate and Spain. Nested scales have been combined, both system (crop, livestock and agri-food system), and spatial (detailed vector map of nitrogen budgets, provincial and national scale). Emissions of the main N compounds have been estimated by crop, management (irrigated and rainfed) and province. This has made it possible to classify the Spanish provinces into different typologies (Rodríguez et al. 2023), as well as to evaluate in an integrated, aggregated and spatialized way alternative nutrient management scenarios at a regional and national scale, considering the efficiency of the management alternatives (Sanz-Cobeña et al. 2023). A multidimensional space of diverse indicators: agronomic (yield and NUE), environmental (emissions of N compounds per hectare and per kg of product) and economic. It is concluded that the diversity of agroclimatic systems and conditions requires the adaptation of agro- environmental and economically sustainable measures. The process of participation with crop and livestock farmers associations, fertilizer companies, administration and NGOs, has been essential for the development of the research and the transfer of results. The main results are displayed and permanently updated on agroscenalab.com.

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https://agroscenalab.com/en/

## Nitrate losses in tile-drained agricultural catchments: insights from insitu sensors and stable isotopes

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### Abstract

Reducing nitrogen (N) losses to water bodies in agricultural catchments remains a challenge. As a result, many water bodies worldwide are polluted with excessive amounts of nutrients, leading to eutrophication, the onset of algal blooms, hypoxia, and fish kills. Despite the technological innovations, many new tools to understand N cycling and transport at high resolution remain inaccessible to researchers working at the field scale due to resource and knowledge constraints. Yet, the policymakers want tangible solutions to reduce N losses, where targets for nutrient loadings in agricultural catchments are unmet. We present ongoing research from Maryland, part of the Chesapeake Bay Watershed, USA, where we are investigating the N losses from agricultural catchments dominant with Maize-Soybean rotation. This watershed has a long history of water pollution stemming from both N and phosphorus, with the Chesapeake Bay alternating in N and phosphorus limitations over a year. The hydrology of the watershed includes overland flow, tile drainage, and open ditch systems. This presentation will focus on tile drainage catchments, where we pair traditional approaches (e.g., autosamplers) with insitu sensors to unravel processes controlling N release and transport. This is being complemented with stable isotopes of nitrate to distinguish the dominant nitrate sources over individual storm events. We will conclude with how our results provide new insights into how the use of traditional approaches, along with new tools and methods, to uncover new knowledge about N fluxes in agricultural catchments to prevent water quality impairment in downstream water bodies.

## Cover crop and nitrogen dose: Measurement of GHG emissions with automated chambers

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### Abstract

Agricultural practices, such as crop management and fertilization, have an impact on soil greenhouse gas emissions (GHG). In recent decades, various techniques have been used to measure soil GHG fluxes. These include micrometeorological and chamber techniques, with the latter being capable of working at smaller field scales. Manual chambers are commonly used for this purpose, but they have important limitations in capturing the high temporal variability that characterises the biological process responsible for soil GHG emissions. Automated chambers, in contrast, provide high temporal soil GHG measurements, but their use is still limited because of the cost and technical challenges of implementation.

This study had the next two objectives, i) to develop an automated chamber system which was validated with measurements obtained with manual chambers. ii) to determine the impact of winter cover crop (CC) use (compared to a bare fallow - F) and nitrogen (N) fertilization (i.e. unfertilized treatment, N0; fertilized treatment, N1) on soil GHG emissions for a sprinkler- irrigated maize (Zea mays L.) system.

The higher sampling frequency of the automated chamber system allowed for the capture of daily fluctuations in flux, resulting in a more accurate estimation of cumulative soil gas emissions compared to the manual chamber system. The CC or N fertilization did not significantly impact on the soil carbon dioxide ($CO_2$) or methane ($CH_4$) emissions during the maize growing season. Conversely, soil nitrous oxide ($N_2O$) emissions were significantly affected by CC and N doses observing the greatest emissions for CC-N1 treatment.

## Assessing nitrate groundwater hotspots in Europe reveals an inadequate designation of Nitrate Vulnerable Zones

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### Abstract

Monitoring networks show that the European Union Nitrates Directive (ND) has had mixed success in reducing nitrate concentrations in groundwater. By combining machine learning and monitored nitrate concentrations (1992-2019), we estimate the total area of nitrate hotspots in Europe to be 401,000 km$^2$, with 47% occurring outside of Nitrate Vulnerable Zones (NVZs). We also found contrasting increasing or decreasing trends, varying per country and time periods. We estimate that only 5% of the 122,000 km$^2$ of hotspots in 2019 will meet nitrate quality standards by 2040 and that these may be offset by the appearance of new hotspots. Our results reveal that the effectiveness of the ND is limited by both time-lags between the implementation of good practices and pollution reduction and an inadequate designation of NVZs. Significant improvements in the designation and regulation of NVZs are necessary, as well as in the quality of monitoring stations in terms of spatial density and information available concerning sampling depth, if the objectives of EU legislation to protect groundwater are to be achieved.

## Lessons from reviewing APSIM's soil nitrogen modelling capability

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### Abstract

The Agricultural Production Systems sIMulator (APSIM) has been used to explore a range of agricultural system questions, including those relating to nitrogen (N) cycling. In the last decade, the focus of model applications has expanded to include environmental impacts of farming. These sustainability aspects 'ask more' of the model and so, to inform and prioritise future development needs, we embarked on a detailed review of APSIM's soil N modelling capability. Being 25 years since the publication of Probert et al. (1998)'s foundational text of APSIM's soil N and residue modules, we could draw on 106 model verification studies across a wide range of systems, applications, and processes. Here we share the lessons learnt.

The review identified strong performance across all modelled processes, despite limited changes to the core of the soil N model since its inception. The model's conceptual pool approach to modelling carbon (C) dynamics with N cycling linked to that via C:N ratios, has proven remarkably versatile. However, these conceptual pools have posed challenges relating to initialisation methods and the resulting sensitivity of predictions at different time scales, e.g. long-term C trajectories vs. short-term seasonal N loss studies. APSIM's adaptable code structure has facilitated the creation of prototypes (e.g., ammonia volatilization and N in runoff) allowing testing ahead of formal release. The review highlights the importance of broad model evaluations across a wide range of applications to ensure their robustness, to identify issues that may be masked in single studies, and to allow the emergence of solutions with broad applicability.

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### Acknowledgements

We acknowledge funding from CSIRO, GRDC and collaborators for project UOQ2204-010RTX. We thank Merv Probert for his vision in developing APSIM Soil N and providing so many of us with lessons on its use that we pass on to next generations.

## Is leachate from stored dairy manure an important nitrogen loss pathway?

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### Abstract

Nitrogen losses from dairy manure generally range from 20-40% (Chadwick et al 2011), with physical barriers recommended to reduce atmospheric gas exchange (Bittman et al 2014).

There is also increasing interest in separating solid from liquid fractions of manure. However, physical barriers may result in anaerobic conditions, increasing methane emissions while solid manure stockpiles may undergo biologically-driven composting and produce nutrient-rich leachate.

Two forms of manure; scraped from a concreted floor in a covered feedpad, and solids separated from yard-wash using a commercial screen and screw-press, were stored in ~1 tonne piles for 318 days uncovered or covered with an impermeable polyethylene sheet (0.15 mm) in a 2 x 2 factorial (manure type x cover) in triplicate in a randomized block design.

Periodically, stockpile weight, moisture, temperature, and leachate volumes were measured with samples collected for chemical analysis.

Significantly greater total C and lower total N losses occurred from separated than scraped manure. Composting within separated solids exacerbated C and N losses and generated large leachate losses (~ 20% of initial mass of separated solids) but were negligible for scraped manure (< 0.2%). Total leachate N from separated solids was 1.5% of initial N and only 0.04% for scraped solids. Covering scraped manure reduced N and C losses but not for separated solids. While leachate N, C (also minerals) concentrations were high compared to natural waters, leaching was not an important N and C loss pathway for stored manure with atmospheric emissions accounting for most C and N losses.

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## Identifying phenotypic traits for the reduction of nitrogen losses from wild barley accessions

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### Abstract

Reducing nitrogen (N) losses and increasing crop N recovery is one of the major challenges to address to increase the resource use efficiency of agroecosystems. Modern crops have been bred to optimize primarily above-ground plant organs under abundant N supply, likely resulting in adverse selection of root traits regarding N uptake (Li et al., 2019). In the present study, we investigated the population Halle Exotic Barley 25 (HEB-25), which consists of 25 wild barley genotypes (Maurer et al., 2015), in search for above and belowground phenotypical traits that enhance N uptake and reduce N losses under reduced N fertilization. We performed a screening experiment under controlled conditions using the 25 wild barley and the elite cultivar of reference, Barke, from the HEB-25 population. The six genotypes which showed the clearest contrasts for biomass productivity and for both above and below ground traits, were selected for a follow-up experiment in which N losses were monitored under conventional and reduced N fertilization rates. The screening experiment confirmed a significant difference in phenotypical traits among the 25 wild accessions. There was a significant effect of the genotypes on nitrate ($NO3^-$) leaching, whereas for nitrous oxide (N2O) emissions, there was a significant effect of genotypes only when interacting with N fertilization as predictor. The genotype HID-380 decreased $NO3^-$ leaching under conventional and reduced N fertilization, and it reduced N2O emissions under reduced N fertilization, compared to all genotypes. The population HEB-25 confirms that phenotypical traits in wild barley genotypes can reduce N losses.

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# Are agronomic and environmental win-wins possible with EEFs? A case study from Australian cropping systems

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## Abstract

Fertiliser application is the largest single variable expense for Australia's grain growers, with nitrogen by far the largest nutrient input. Nitrogen losses as $N_2O$ also represent the single largest source of scope 1 and 2 emissions, with fertilizers contributing 38% and crop residues 20% to total on farm emissions. Here we summarize 10 years of research into the NUE, N loss and economics using enhanced efficiency fertilizers to achieve this dual objective.

The fate of fertiliser N across crop uptake, soil residual N and N losses was determined using the $^{15}N$ recovery technique over nine trials with four N rates (0, low, medium and high industry rates) over 3 years in dryland sorghum. Average seasonal crop uptake efficiency ranged from 50% at the low and medium N rate (80 kg N $ha^{-1}$) to < 38% at the highest N rate, and was as low as 5%. Nitrogen losses averaged 26.5% across all rates and trials. At the medium N rate, losses exceeded 18% in all trials, despite relatively dry seasons, and in some trials exceeded 34% (Rowlings 2022).

Automated chamber measurements showed EEF's reduced $N_2O$ emissions, with DMPP as the most effective reducing emissions repeatedly by 60-80%. However this failed to translate into either increases in absolute yield or plant uptake (Lester 2016), or greater residual N uptake by subsequent crops (Dang 2021).

In order to fully utilize the benefit of EEF's, the complex interaction between fertiliser chemistry in banded systems, soil water availability and crop N uptake with N loss pathways needs to be reconciled.

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## Seasonal variability of nitrate concentrations below the root zone: A monthly predictive modeling approach

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### Abstract

The NLES5 model is used in Denmark for estimating annual nitrate leaching from the root zone on a national scale. The model is based on leaching data obtained by the product of the measured nitrate concentration below the root zone depth and the percolation calculated using a hydrological model. However, this approach may have some limitations, including redundancy and unclear error propagation in the relationship between nitrate concentration and percolation. In addition, it does not consider seasonal variations. This study presents an approach for estimating the monthly distribution of nitrate concentration, which is independent of the water flow calculations. The proposed workflow includes screening algorithms to identify the most relevant predictors, testing the predictive performance, simplifying the number of predictions for practical implementation, and evaluating the impact on the final N leaching calculations. The workflow was applied to data from suction cup measurements found in the NLES5 support database of experimental sites. The results indicate that the XGB (Extreme Gradient Boosting) tree-based algorithm effectively estimates monthly variations in nitrate concentration without relying on loading data. This is achieved by using temporal, management, soil, and weather covariates such as month, mineral nitrogen fertilization in spring, main crop, winter crop, clay content, mean monthly temperature and accumulated precipitation in the harvest year. A cross-validated error of 31 % for nitrate concentration was achieved, and a correlation ($R^2$) of 0.8 with N leaching calculated from observed concentrations, demonstrating a consistent description of the seasonal distribution of nitrate concentrations below the root zone.

## Improving the estimation of ammonia emissions from synthetic fertilizers – new Tier 3 methodologies for emission reporting

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### Abstract

Significant ammonia emissions can occur when synthetic nitrogen fertilizers are applied to the soil surface. The latest Tier 2 methodology, provided for reporting national ammonia emissions under United Nations and European Union legislation (European Environment Agency, 2023), is based on the analysis of a database of emission measurements from indoor and outdoor experiments. This found significant effects of fertilizer category (granular urea- based, liquid urea ammonium nitrate, granular higher emission ammonium-based e.g. ammonium sulphate, granular lower emission ammonium-based e.g. ammonium nitrate), application method (broadcast, incorporated, injected), soil pH, location (indoor/outdoor) and the measurement method used. However, a database with 2776 ammonia emission measurements also allows the development of a wider range of statistical models.

An investigation of the variance remaining after accounting for the effects previously identified found additionally significant effects of the soil clay content, rainfall and air temperature. Here we describe the range of different models developed and the challenges associated with their use. Using these models as part of Tier 3 methodologies would allow both farmers and policymakers to identify situations with a high risk of substantial ammonia losses and thus target abatement measures. However, the benefits of a more cost effective implementation of abatement measures needs to be traded off against the additional costs associated with the models' requirement for  data on the date and location of applications.

This trade-off will be situation dependent but is likely to reduce with time, as the data required become increasingly available from the digital platforms of modern agricultural machinery.

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## Establishing the fertiliser N budget in Australian grain systems – informing APSIM using $^{15}N$ recovery data

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### Abstract

Biogeochemical models are an important tool to predict how farming practices influence productivity, nutrient use efficiency and nutrient losses to the environment. However, many simulation exercises lack the observed data to sufficiently validate overall N dynamics from both soil and fertiliser sources and rely on single or a few measurable N pools, potentially shifting bias from one pool to another. This study evaluated APSIM's ability to simulate N fertiliser budgets in dryland sorghum and wheat systems of eastern Australia using an extensive $^{15}N$ recovery dataset from 18 field trials with up to four N rates. Modifying the parameters related to denitrification and mineralisation rates improved the agreement between simulated and observed fertiliser N loss, resulting in 13.1 kg N ha$^{-1}$ of RMSE. Nevertheless, the discrepancy between observed and simulated values for fertilizer N recovered in soil or plant, or lost from the system increased with increasing N rates, up to 30% of applied N at specific trials. This study demonstrated the use of $^{15}N$ recovery data to inform biogeochemical models and the shortcomings of the model largely reflecting the absence of suitable temporal experimental data, especially for N mineralisation, NH3 volatilisation and denitrification (N2+N2O) and their sources (i.e. soil, residue and fertiliser). Improving capabilities of biogeochemical models to simulate N cycling requires a concerted effort in experimental and modelling research to support development of farming strategies to reduce N losses.

## Uncertainty in model predictions of ammonia volatilization from field-applied animal slurry

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### Abstract

Mathematical models are used to estimate ammonia loss from field-applied animal slurry for emission inventories and fertilizer budgets. Estimation of associated uncertainty is difficult and, when done, often based on simple assumptions. But evidence of consistent measurement differences among the institutions that have made measurements suggest that uncertainty is not trivial and that estimation requires measurements from multiple sources. This work presents an approach for estimation of emission uncertainty using the ALFAM2 model (Hafner et al., 2019). Model parameters were developed by fitting emission predicted using the ALFAM2 R package (https://github.com/AU-BCE-EE/ALFAM2) to about 17000 emission rate measurements from more than 600 field plots made by 16 research institutions in Europe, all from the public ALFAM2 database (https://www.alfam.dk). The general bootstrap approach of Sohn and Menke (2002) was used with resampling at the research institution level to generate a large number of plausible parameter sets that reflect variability in measurements among institutions. These parameter sets are included in an updated version of the ALFAM2 R package and can be used to estimate uncertainty for any combination of input variables. Uncertainty in model inputs, such as weather or slurry application rate, can be combined with parameter uncertainty to estimate overall uncertainty in model predictions (Abdi et al., 2023). Resulting predictions from the model show significant uncertainty in absolute emission and also relative effects. The approach described here may be useful for estimation of uncertainty in inventories and for identifying specific predictor variables with large effects on uncertainty for future research.

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## A modelling approach to evaluate mitigation measures on N leaching and groundwater nitrate concentration in the Netherlands

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### Abstract

N leaching is a major source of N loss and nitrate contamination to groundwater. In the sandy and loess soil regions of the Netherlands, the average nitrate concentrations in groundwater have been in exceedance of the 50 mg/L limit of the EU Nitrates Directive in the past years (Fraters et al., 2021). Thirty-four groundwater protection areas are identified as in risk of nitrate leaching, and mitigation measures must be evaluated for these areas. While field trials are expensive and time-consuming, we adopted a modelling approach to simulate field N leaching as affected by management practices.

SWAP-ANIMO are process-based models, using climate, soil, and farm management information to simulate water flows, and the transport and transformation of N across the soil-plant-atmosphere interfaces (Groenendijk et al., 2005). Four types of mitigation

measures were modelled: (1) Reduction of fertilisation levels; (2) Adaptation of crop rotation, where crops prone to leaching were replaced by plants with higher N use efficiency (e.g., continuous silage maize to grassland or rotation of grassland and maize, additional fibre crops following potatoes, etc.); (3) Farm management measures (e.g., reduced grazing, introducing catch crops, recycling of crop residues, etc.); and (4) Shift of farming system from conventional to organic production. Simulations ran for 30 years assuming current climate conditions.

Results from the modelling were communicated to stakeholders and policymakers, and modelling scenarios were further improved based on feedback. The outcome will be used to facilitate policymaking, and for selecting potential measures for further investigation.

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## Effect of an urease- and a nitrification inhibitor on ammonia and nitrous oxide losses after urea-ammonium-sulfate application

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### Abstract

In order to reduce ammonia ($NH_3$) emissions from the application of urea fertilizers, the German Fertilizer Ordinance stipulates the use of a urease inhibitor (UI). Although under discussion, urea-ammonium-sulfate (UAS) does currently not subject to these requirements. To improve the knowledge on the environmental effects of UAS and inhibitors, we conducted a field experiment on a Haplic Luvisol with the following treatments: unfertilized control (0N), UAS only, UAS with an UI (2-NPT), and UAS with UI and a nitrification inhibitor (NI) (MPA). We determined $N_2O$ fluxes over three full years and $NH_3$ emissions in campaigns after N application. In each experimental year, measurements were conducted in all crops of the crop rotation maize – winter wheat – winter barley.

Ammonia losses varied between 0.05 (UAS+UI) and 32 (UAS without inhibitor) kg $NH_3$ N $ha^{-1}$ and sampling campaign, with a mean $NH_3$ emission factor of 6%. Except for winter wheat in 2023, the addition of an UI to UAS decreased cumulative $NH_3$ emissions significantly. Mean reduction capability of the UI compared to the non-inhibited UAS was 43%.

The cumulative $N_2O$ emission ranged between 0.13 and 4.2 kg $N_2O$-N $ha^{-1}$ $a^{-1}$, whereas the mean $N_2O$ emission factor was determined as 0.42%. The addition of a NI to UAS reduced cumulative emissions between 5 and 54% whereas differences between the inhibited and the non-inhibited treatment were not always statistically significant. The mean reduction of $N_2O$ emissions due to NI addition was 33%. None of the inhibitor additions increased the N use efficiency.

## Seasonality, drivers and their legacy effects on N2O emissions from managed grassland in Finland

Mari Pihlatie[1,2], Asta Laasonen[3], Mika Korkiakoski[4], Henriikka Vekuri[4], Heidi Aaltonen[1,2], Tatu Polvinen[1,2], Miki Sirola[1,2], Noora Manninen[1,2], Markku Koskinen[1,2]

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### Abstract

Changing climate and strong weather variability threaten the capacity of agricultural ecosystems to mitigate climate change. Grassland ecosystems on mineral soils are typically carbon neutral, however, management practices and high year-to-year weather variability may strongly influence the greenhouse gas budget and especially the emissions of nitrous oxide (N2O). We measured CO2 and N2O fluxes and soil and environmental variables at the SMEAR-Agri research station on a managed grassland in south Finland. The SMEAR-Agri station is built at Viikki Research Farm of the University of Helsinki on fine textured mineral soil cultivated with grass silage. The fluxes of H2O, CO2 and N2O are continuously measured by eddy covariance, and the flux data is supported with automated meteorological and soil measurements that include temperature, moisture, electrical conductivity, redox profiles, and water table depth.

Here, we present continuously measured N2O fluxes over two years (2022-2023) and reflect their responses to soil and environmental variables, weather, and grassland management.

Daily dynamics of N2O emissions from 2022 show that the emissions during snow melt increase with soil temperature, which co-occurred with a decreased redox potential to the level optimal for N2O production. The highest N2O emission peaks were observed in early June, almost two weeks after mineral nitrogen. In 2022-2023, the grassland was renewed with a spring crop undersown with a grass mixture. As expected, the N2O emissions followed changes in soil moisture and redox potential, however, the highest emissions were measured after the cereal harvest in September. These distinctly different years with seasonally variable N2O emissions show the importance of assessing both the immediate responses of N2O to soil conditions but also the legacy effects of soil conditions and agricultural management.

## Reducing denitrification losses from intensively managed sugarcane systems

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### Abstract

High fertilizer N inputs and a warm and wet climate render sugarcane systems prone to N loss via denitrification. Here we present a synthesis of studies using high temporal resolution $N_2O$ data, isotope methods and biogeochemical models to constrain $N_2O$ and $N_2$ emissions in sugarcane systems, highlighting options for N loss mitigation. Losses of $N_2O$ were driven by excess nitrate, exhibiting a non-linear increase with increasing N rates. Nevertheless, $N_2$ was the main product of denitrification with $N_2O/(N_2O+N_2)$ ratios ranging from 0.03 to 0.19.

However, $N_2O$ dominated denitrification in acidic sugarcane soils, even under flooded conditions. Liming reduced denitrification loss and shifted the $N_2O:N_2$ ratio towards $N_2$, demonstrating environmental and agronomic benefits. Even though environmentally benign $N_2$ accounted for up to 78% of N fertilizer losses, the $^{15}N$ fertilizer balance showed that this percentage decreased with increasing N rates. Long-term simulations indicated N mining in systems where sugarcane residues were burnt. The benefits of residue retention are however partially offset by increased denitrification losses. The use of a nitrification inhibitor reduced these losses from the N fertilizer band by 70%, and shifted the $N_2O:N_2$ ratio towards $N_2$, highlighting an effective strategy to reduce N loss while keeping the benefits of cane trash retention. The observed response of reactive and non-reactive N losses to increasing N rates highlights the soil specific need to optimize soil pH and N substrate availability when seeking to improve agronomic efficiency while reducing the environmental footprint of intensively managed sugarcane systems.

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## Improve air quality by adjusting nitrogen fertilization practices: the key role of dynamic bottom-up spatial inventories towards cost-benefit assessments

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### Abstract

It is becoming increasingly urgent to reduce ammonia emissions to protect both the environment and human health. Social acceptability of abatement measures is nevertheless a prerequisite to their implementation and implies being able to target the most cost-effective ones. It is particularly difficult to anticipate the effectiveness of nitrogen fertilization abatement practices: they are most variable in time and space, depending on the type of product, the type of use, and soil and weather conditions. It is thus essential to have a set of tools that can be used to trace the effects of any change in cultural practices from ammonia emissions reduction up to health effects avoided due to less human exposure to particulate matter. We built such a tool by coupling a dynamic bottom-up spatial inventory for France, Cadastre_NH3, a chemistry transport model, CHIMERE, and a health impact assessment tool, Alpha-Risk-Poll. We used it together with monetizing avoided emissions and yield gains, as well as health benefits to assess the substitution of a high volatilization fertilizer by a low one. We showed how health benefits more than offsets the mitigation costs even for a little effective measure. This tool can thus be used to provide objective input into democratic debates on the political choices to be made in terms of incentives and support for farmers for more sustainable practices. Thanks to Cadastre_NH3 it has the specific potential of assessing the effects of practices either in isolation or in combination, which is of great interest in the decision-making process.

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## Towards understanding the fate of excess Nitrogen in the terrestrial system under a warming climate

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### Abstract

Decades of agricultural intensification across Europe have created nitrogen legacy stores that continue to threaten the functioning of aquatic ecosystems and human health. Climate change further aggravates the fate of nitrogen export and retention in the terrestrial system (e.g., soil, groundwater, and rivers) - the extent of which is yet not fully understood. Herein we provide a continental-wide analysis of nitrogen retention and export across European landscapes to receiving water bodies using changing climate, hydrology, and socioeconomic scenarios. We employed a range of CMIP climate scenarios (RCPs; 2.6 to 8.5) coupled with different socioeconomic projections (SSPs; 1 to 5) of future nitrogen inputs to drive an integrated hydrology and water quality model (mHM-mQM; Nguyen et al., 2022) – that allows tracking the fate of excess nitrogen in soil, groundwater, and aquatic systems. Our investigation spans over the period ranging from 1970 to 2070s. Our continental-wide analysis projects a considerable reduction in nitrogen levels across European water bodies by the middle of the century (2050s). Improvements are attributed to technological advancements (wastewater treatment plants) – in Eastern Europe and - a reduction in diffuse nitrogen inputs in Western and Central European regions. Despite the improvements, we still find a substantial proportion of European water bodies that may exceed critical nitrogen concentration thresholds (e.g., 2- 3 mg N/l) – attributed to gradually depleting nitrogen from legacy stores (e.g., groundwater). We call for the adoption of proactive actions focused on reducing excess nitrogen as well as strategies for managing and mitigating the depletion of legacy storage.

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## Denitrification in groundwater is the key to targeted agricultural nitrogen management

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### Abstract

Globally, food production for an ever-growing population is a well-known threat to the environment due to losses of excess reactive nitrogen (N) from agriculture. Since the 1980s, many countries of the Global North, such as Denmark, have successfully combatted N pollution in the aquatic environment by regulation and introduction of national agricultural one-size-fits-all mitigation measures. Despite this success, further reduction of the N load is required to meet the EU water directives demands, and implementation of additional targeted N regulation of agriculture has scientifically and politically been found to be a way forward. In this presentation, we present a comprehensive concept to make future targeted N regulation successful environmentally and economically. The concept focus is on how and where to establish detailed maps of the groundwater denitrification potential (N retention) in areas, such as Denmark, covered by Quaternary deposits. Quaternary deposits are abundant in many parts of the world, and often feature very complex geological and geochemical architectures. We show that this subsurface complexity results in large local differences in groundwater N retention. Prioritization of the most complex areas for implementation of the new concept can be a cost-efficient way to achieve lower N impact on the aquatic environment. This presentation will cover the synthesis of a large Danish study called MapField just published in Nature Scientific Reports (Hansen et al. 2024).

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## The Canadian Inventory for Ammonia Emissions from Agriculture: Successes and Challenges

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### Abstract

Canada's agricultural industry is a large producer and exporter of grains, beef cattle and pigs, while the dairy and poultry sectors are smaller because of limited exports. As a signatory to the Convention for Long-Range Transboundary Air Pollution (CLRTAP), Canada reports ammonia emissions to the UNECE. Although designated a Criteria Air Pollutant, ammonia emissions are not regulated in Canada. The national emission inventory is calculated monthly for key agricultural sectors and ecoregions, and emissions are allocated amongst 3300 land polygons. Emissions are greatest from fertilizers (39%) and beef sectors (30%). Emissions have grown steadily over years (24% from 1981-2021), recent increases are due mainly to increased use of fertilizer, especially urea. Large variations in monthly emissions are due to seasonal differences in farming activities and temperatures (Bittman et al. 2023) and are now visible from space (Shephard et al. 2023). Monthly emission values are used in atmospheric modelling and help suggest impact and mitigation. Three of the emission hotspots in Canada are located near the largest urban centres and are associated with dairy and poultry production. Ammonia emissions are used also for calculating nitrogen budgets (Yang et al. 2023). While Canada has no policies for reducing ammonia emissions, farm activity surveys identified practices that coincidently reduce emissions, such as staged feeding, side-banding commercial fertilizer and increasing leguminous crops. Increasing winter-grazing by the beef sector helped reduce emissions from manure handling. More comprehensive farm activity data will help track adoption of promising practices like low-emission manure application and fertilizer inhibitors.

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## Mechanisms of Nitrogen Loss Reduction Within Intensified Agriculture Systems

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### Abstract

Sustainably intensified agriculture (SIA) fosters the principle of maximum profit, while minimizing environmental losses of nutrients. Cover crops have been identified as a highly effective practice to foster SIA in row crop agricultural systems of the Midwest USA. Thus, the goal of this presentation is to share findings from long-term on-farm and watershed scale cover crop research in Central IL and Southern IN in nutrient loss reduction and yield protection. Over a 9-year period on the field scale, we have observed a 40-49% reduction in total nitrate load and flow weighted NO3-N concentration. Furthermore, we observed a 50% reduction in environmental cost as it relates to losses of NO3-N and N2O. At the watershed scale, inclusion of cover crops on 50% of the row crop area resulted in 33-48% reduction in nitrate loss via sub-surface drainage and a 38% reduction in NO3-N loss via surface drainage. As it pertains to yield protection, the inclusion of overwintering legumes generated an average of 118 kg $ha^{-1}$ of N in the above ground biomass, which resulted in a 100 and 50 kg $ha^{-1}$ less N fertilizer needed to achieve optimal corn yield, respectively, relative to the no cover crop and cereal rye treatments. Results from these studies demonstrated that impact of cover crops to reduce NO3-N via sub-surface drainage is scalable and biologically fixed N from legume cover crops has the potential to achieve optimal yield with a lower requirement N fertilizer.

## More than 30 years of wetland restoration in Denmark: modeling the effect on nitrogen removal and future perspectives

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### Abstract

Wetland restoration plays a crucial role in mitigating nitrogen losses from agricultural fields (Hoffmann et al., 2020; Nilsson et al., 2023). Here we conducted a comprehensive study on nitrogen (N) removal in 36 Danish rewetted wetlands, each monitored for at least one year. Our aim was to develop general empirical models for monthly and yearly N-removal in rewetted wetlands. Using a linear regression model, we characterized monthly and yearly nitrate ($NO3^-$) and total N (TN) removal efficiency (%). Monthly removal efficiency in our wetland model is influenced by water flow, N concentration, and air temperature, explaining 39% and 33% of the variation for $NO3^-$ and TN respectively. The yearly wetland model accounts for 31% and 32% of the variation in $NO3^-$ and TN removal efficiency, respectively. On average, yearly $NO3^-$ and TN removal amounted to 110 and 130 kg N $ha^{-1}$ $year^{-1}$, respectively. Despite confirming the effectiveness of rewetted wetlands in mitigating N, our results demonstrate that a decrease in N removal has appeared during the last three decades for wetland restoration projects in Denmark. This trend may be a result of lowered governmental N mitigation criteria for wetland restoration projects to increase the area of land eligible for N restoration schemes. Furthermore, we speculate that future wetland restoration projects emphasizing a more climate mitigation-oriented perspective, will further decrease the average N removal from Danish wetlands. This highlights the need for additional measures to address N losses from agriculture, as current efforts seem insufficient to meet the regulatory requirements of reaching good ecological status in most Danish coastal waters (Thodsen et al., 2023).

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## 1.4 Session 3 - Nitrogen recycling

### 1.4.1 Keynote: Xin Zhang "Decarbonization in a eutrophic world"

Xin Zhang is an Associate Professor at the University of Maryland Center for Environmental Science. She holds a Ph.D. in environmental science from Yale University and held a post-doctoral position at Princeton School of Public and International Affairs. The goal of Xin's research is to evaluate how socioeconomic and biogeochemical processes affect the global nutrient cycle and the sustainability of agricultural production and, in turn, provide policy input on mitigating nutrient pollution while meeting global food and biofuel demands.

Xin has published papers on various peer-reviewed journals (e.g., Nature), and have received grants from multiple institutions (e.g., National Science Foundation).

Decarbonization in a eutrophic world

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Abstract

Decarbonization is critical for combating climate change, but likely has profound impacts on nitrogen cycles, which are already distorted by human impacts. Few studies have systematically assessed a wide range of impacts of decarbonization strategies on sustainable use of nitrogen. Thus, we reviewed major decarbonization opportunities and their divergent needs for nitrogen use, revealing the complex interconnections between managing carbon and nitrogen cycles. Our review shows that some decarbonization strategies, such as reducing carbon-intensive synthetic N fertilizer use, can be win-win for mitigating carbon dioxide emission and nitrogen pollution. In contrast, decarbonizing energy supply with ammonia and biofuel, without advances in nitrogen management in agricultural and industrial sectors, could largely increase nitrogen losses to the earth system, further exacerbating pervasive eutrophication problems. The advent of "green ammonia," produced using renewable energy, is a promising marine transport decarbonization option but could triple the amount of reactive nitrogen that humans introduce to the biosphere. Meanwhile, green ammonia could lead to the decentralization of fertilizer production, thus increasing the accessibility of fertilizer; however, its effect on fertilizer use efficiency and eutrophication remains uncertain.

After all, decarbonization efforts should not be at the cost of further eutrophicating the world. To address the two major threats faced by humanity, climate change and eutrophication, it is important to improve our understanding of the interconnection between human impacts on carbon and nitrogen cycles, systematically assess existing decarbonization strategies, and continue to improve the nitrogen use efficiency in the agriculture-food system. In response, the Global Nitrogen Innovation Center for Clean Energy and the Environment (NICCEE), with joint funding from the U.S. National Science Foundation, U.K. Research and Innovation, and Natural Sciences and Engineering Research Council of Canada, has been established. Its mission is to enable and accelerate social and technological innovation for sustainable and climate-smart nitrogen management in agriculture-food-energy systems, including the urgent need to respond to the challenges and opportunities of the impending technological innovation of green ammonia.

### 1.4.2 Oral presentations

# Human N excretions as fertilizers in France: current situation, potential, and geospatial matching

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## Abstract

Nitrogen excreted by humans, especially urine and urine-based fertilizers, can be used as an efficient fertilizer[1], but is seldom recycled in current Western sanitation systems.

We first present a full N-budget of the current French sanitation system[2], based on a full dataset of the 20,000 wastewater treatment plants (WWTP). Only 10% of excreted N is recycled through WWTP sludge, 50% is lost in the air, and 40% is lost in waters and the ground. In France, recycling all urine (~250 ktN) could replace 10-15% of the current N mineral fertilizers consumption. In other large European countries, this rate is around 15- 30% (Spain, Germany, UK) or as high as 40% (Italy).

Beyond this national-scale flows assessment, we then finely analyze the spatial matching between excretions (where people are) and crops fertilization. To do so, we use a geodatabase of all the French agricultural parcels, and combine it with empirical surveys of French farmers practices. This bottom-up method is in very good accordance (>90%) with FAO data on N mineral fertilizers use.

We find that most (~2/3) of French excretions could be spread withinin a radius of less than 10 km. We identify the regions of concerns regarding inadequate supply/demand: the Paris region and the Mediterranean French Riviera. We use our computed distribution of distances to discuss the most adapted urine recyling method, depending on the cases: raw storage and spreading of urine or concentration before transport.

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## Recycling Nitrogen from urban wastes to organic farming – a scenario analysis

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### Abstract

The EU aims to expand organic farming to 25%, yet the sector faces constraints in nutrient availability, particularly phosphorus and nitrogen. Societal waste, such as household compost and sewage sludge, contains valuable nutrients for organic farming but requires assessment for nitrogen availability, carbon storage, and contamination risks (e.g., heavy metals). Existing field trials often lack organic management practices, hindering accurate evaluation. To address this gap, a 100-year scenario analysis using the DAISY soil-plant-atmosphere model assessed four crop rotations with varying reliance on legumes, applying different nitrogen rates from various waste sources (household waste compost, sewage sludge, stored human urine) and controls (cattle manure, slurry, deep litter, and mineral fertilization). The model was validated using results from the CRUCIAL trial (Magid et al., 2006). Short-term nitrogen recovery rates ranged from 50-60%, increasing to 60-70% in the long term. Deep litter, cattle manure, and compost had the lowest values followed by sewage sludge, human urine, cattle slurry, and mineral fertilization. Nitrogen losses accounted for 34-40% of applied nitrogen, following the same pattern. The opposite trend was seen for the carbon sequestration factor (compost=0.39, manure and deep litter=0.12, sewage sludge=0.09, slurry=0.02). Compost and sewage sludge resulted in surplus Cd and Cu, while Zn levels also increased for the animal manures. Yet, levels remained below EU thresholds after 100 years of continuous application. The study underscores the suitability of societal waste for organic farming, emphasizing the trade-off between nitrogen fertilizer value and carbon storage.

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## Current status nitrogen cycling arable farms in the Netherlands in relation to environmental effects

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### Abstract

Dutch agriculture has been famed for its production output, but it also has the greatest environmental impact in Europe. Increasing nutrient cycling may enable to maintain high yields while reduce the losses to the environment. In this study we assess the current status of Nitrogen (N) cycling (i.e., through re-use of crop residues and/or green manure) in Dutch arable farms and fields and relate these to management characteristics and crops. Crop production and fertilisation data from 38 arable farms spread over the Netherlands for the year 2022 was used for this.

We show that arable fields have a wide range of N cycling values, while this range is much narrower on farm level. As inherent to arable systems, product output is removed from the field, and only crop residues may remain in the field. If crop residues are minimal (e.g. onion) or removed (straw), circularity values are generally lower. The system is thus very linear, with an average cycled flow of only 34% on field level and 30% on farm level. However, N cycling can be greatly improved when a green manure crop is sown after the main crop.

Furthermore, we found that arable farms with a higher N use efficiency and N cycling emitted less GHGs per unit product output and had lower N leaching.

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## Predicting cover crop nitrogen residual effect to optimize fertilizer reductions

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### Abstract

Cover crops can contribute to climate change mitigation by promoting soil organic carbon sequestration and lower greenhouse gas emissions from reduced fertilization of following crops. Their nitrogen fertilizer replacement value (NFRV) varies based on cover crop type and management. This study aimed at quantifying the NFRV of different cover crop types and management, to guide N fertilizers reduction. Ryegrass (Lolium perenne L.; RG), plantain (Plantago lanceolata L.; PL), red clover (Trifolium pratense L.; RC), and two mixtures (RG+PL and RG+PL+RC) were sown in May 2020 and 2021 and terminated by rotovation followed by deeper ploughing or directly by ploughing before sowing the following crop. To quantify NFRV, cover crop plots were not fertilized and control plots received 0, 50 and 100 kg mineral N ha$^{-1}$. In both years, RG+PL+RC had the greatest aboveground biomass and N in autumn (5.5 Mg ha$^{-1}$, 128 kg N ha$^{-1}$), while RG had the lowest (0.7 Mg ha$^{-1}$, 21 kg N ha$^{-1}$). Differences between cover crop types were less pronounced in spring, before termination. Termination method didn't affect NFRV, which was significantly correlated to cover crop biomass ($p<0.001$) in autumn ($r=0.83$) and spring ($r=0.66$). NFRV was as high as 100 kg N ha$^{-1}$ with RC and RG+PL+RC, while negative values were obtained with autumn biomass below 1 Mg ha $^{-1}$. The strong correlation between cover crop biomass and NFRV can guide N fertilization reduction, while the 1 Mg ha $^{-1}$ threshold confirms the need for a minimum cover crop biomass for providing desired ecosystem services[1,2].

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## Agronomic performance of Nitrogen-rich, biobased fertilizers across European field trial sites

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**Keywords:** Residual fertilizer effect, Agronomic efficiency, Nitrogen fertilizer replacement value, Nitrogen use efficiency, Crop yield.

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## Abstract

Substituting mineral fertilizers with novel biobased fertilizers (BBFs) produced from various organic waste and side streams may reduce the environmental and climate impacts of fertilizer production and use. Furthermore, potentially wasted nutrients could be recycled this way. For the substitution to be beneficial for farmers, the environment, and the food security, the BBFs need to be effective and reliable. However, the agronomic performance of novel commercially available BBFs has not yet been well studied.

The agronomic performance of seven commercial nitrogen-rich BBFs at four field sites across Europe (Finland, Denmark, Germany and France) and two growing seasons (2021, 2022), covering different climates, soil types, and crop rotations, was investigated. Additionally, two or three local BBFs were tested at each site. The same experimental design (randomized block design, n=4) was applied at all sites. In addition, 4-5 reference treatments with synthetic N-fertilizers at increasing levels were included.

The BBFs had agronomic performances with an average mineral N fertilizer replacement value (NFRVAE) of 70% across all sites and years. Variations in the agronomic performance of the BBFs were observed between the trial sites and years. Still, in general, no significant differences in yields were found compared with the mineral N fertilizer reference applied at the same total N level. The BBFs tended to have a higher NFRVAE when incorporated compared to surface application. The residual effect of BBFs in the year after application was not significantly higher for any of the BBFs than that of the mineral N fertilizer.

**Acknowledgment:** This study was funded by the European Union's Horizon 2020 research and innovation program under grant agreement No 818309 (LEX4BIO).

## Sustainable management of animal manure and biogas digestate using separation and pyrolysis technology: A field study evaluating N fertilization and $N_2O$ emission of pig manure and digestate slurries, liquid fractions and biochars

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### Abstract

Significant environmental impacts are associated with the management of animal slurry and biogas digestate especially in terms of GHGs evolved throughout the management chain. Slurry separation and pyrolysis, a potentially beneficial technology, involve removing large proportion of dry matter from slurry to produce biochar, but there is limited information on its effects on soil nutrient dynamics and $N_2O$ emissions. We conducted 2-year field experiment (8 treatments, crops, winter barley, & winter wheat) to evaluate the impact of biogas digestate, pig manure slurries, their liquid fractions, and biochars on soil $N_2O$ emissions and crop yield. Barley and wheat yield ranged between 2-5 and 8-12 t-$ha^{-1}$, respectively. The crops yield among treatments utilizing digestate, its liquid fraction and biochar as amendments was comparable to mineral fertilizer. In contrast, barley yield was significantly lower in plots treated with pig manure and its biochar, while wheat yield decreased in plots amended with pig manure. Temporal soil $N_2O$ emission rates were significantly higher in liquid-based treatments immediately after amendments. However, the cumulative and yield scaled $N_2O$ emissions were significantly higher for pig manure than for mineral fertilizer in both years. The yield scaled $N_2O$ emissions of pig manure were 1.82 and 0.19 Kg-$N_2O$-N-$t^{-1}$ in barley and wheat, respectively. Overall, dry matter separation of digestate and amending soil with liquid fractions and biochar is a promising management practice for maintaining crop yield with relatively low yield scaled $N_2O$ emissions. However, using pig manure fractions require further investigation due to variable impacts on $N_2O$ and yield.

## Fishery waste-derived organic fertilisers as alternatives for nitrogen fertilization

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### Abstract

Fish and aquaculture industries offer great potential to recover valuable fertilising products from their waste streams using technologies such as bokashi fermentation, hydrolysis, and biodrying. This study explores the potential of utilizing organic fertilisers derived from fishery waste and by-products from six representative European fishery sectors as alternatives to synthetic nitrogen (N) fertilisers, thereby potentially lowering environmental impact related to global warming. Total N content of the organic fertilisers ranged from 1.9% to 9.8% by mass, predominately organic N. A four-month incubation experiment revealed that organic fertilisers containing easily degradable N sources, such as protein fraction and amino acids, exhibited a higher mineralization rate (49-66%) than the other fertilising products (10-35%), resulting in enhanced N availability in the short term. Since the biogenic C from organic fertilisers mineralization does not contribute to the net increase in atmospheric $CO_2$ to life cycle assessment (Egene et al., 2022), we hypothesize that these organic fertilisers would have lower global warming potential compared to their synthetic counterpart. To test this hypothesis, a follow-up experiment will monitor the gaseous emissions of ($CH_4$, $N_2O$ and $NH_3$) from these organic fertilisers. Results of these experiments will provide insightful information for the agronomic value and environmental impact of utilising fishery waste-derived organic fertilisers as a potential replacement for synthetic fertilisers.

Keywords: fishery waste; organic fertiliser; nitrogen mineralization; greenhouse gas emissions

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## Partial replacement of mineral N fertilisers with animal manures in an apple orchard

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### Abstract

Partial substitution of mineral fertilisers (MF) with animal manures is a good alternative to reduce MF use and increase both nutrient cycling and soil organic matter content. A three-year field experiment was conducted in a Portuguese apple orchard to assess the impact of this practice on crop performance, soil fertility and greenhouse gas emissions. The treatments consisted of a control (CTRL, 100% mineral N) and four manure treatments (50% mineral N + 50% manure N): cattle slurry (CS), acidified cattle slurry (ACS), cattle solid manure (CsM) and poultry manure (PM). The results showed that the partial replacement of MF with manures increased soil organic matter and total mineral N content compared with the CTRL, but leaf N absorption was lower in the manure treatments. Fruit N absorption was, however, not impacted. Fruit weight and size, which determines the market value for apples, were also not affected. Replacement with CsM and PM also increased β-glucosaminidase activity in the soil. CS showed a slightly higher crop productivity compared with CTRL; however, the opposite was found for CsM. The manure treatments emitted more $CO_2$ and $N_2O$ than the CTRL, but this increase was not observed in all years. Due to its composition, PM was the highest emitter of $N_2O$. Only CS (20.49 t $CO_2$-eq $ha^{-1}$) and CsM (20.30 t $CO_2$-eq $ha^{-1}$) showed comparable global warming potential (GWP) to the CTRL (19.49 t $CO_2$-eq $ha^{-1}$). Considering fruit production and GHG emissions, CS emerged as the best solution to partially replace MF in apple orchards.

### Acknowledgements

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## Fish sludge as fertilizer

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### Abstract

Fish sludge is a residue from aquaculture, containing fish feces and feed spill. The composition of fish sludge depends on the raw material of fish feed and the fraction of feed spill, as well as the salinity of the water (marine/salty or brackish). Fish sludge is usually filtered, dewatered and dried. However, some fish sludge is also used in biogas production or composted and then used as fertilizers.

Fish sludge contains nitrogen, but mostly on organic form, and nutrient content is unbalanced (Brod et al. 2018). Anaerobic digestion increases nitrogen availability (Brod et al. 2017; Foereid et al. 2021). Most research so far has been performed in pot experiment or field experiments in Norway only, and with grain or grass as test crop. In the SEA2LAND project, fish sludge has been tested as fertilizer for broccoli in field experiments, repeated in five European countries (Norway, Estonia, Belgium, France and Spain). Pelleted fish sludge was tested in all countries, and a pelleted mixture of fish sludge and other products was tested in Norway. Application rate was determined based on nitrogen availability found in a preceding pot trial. However, in the field trials, performance varied widely between sites. The causes of this will be further investigated under controlled conditions. A pot trial comparing fish sludge and digestate of fish sludge on nitrogen utilization and greenhouse gas emissions is being performed. Results from the field trial and selected pot trials will be presented and discussed.

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## Coagulants and flocculants remove nitrogen from diluted dairy manure.

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### Abstract

Separating the solid fraction from farm dairy effluent reduces the effluent volume and facilitates its transportation to more distant areas for land application, contributing to better nutrient redistribution on the farm. Few studies have investigated solid-liquid separation for the Australian dairy industry. This study aims to compare the effect of five coagulants and flocculants on removing nitrogen from farm dairy effluent. We performed jar test experiments using Tanfloc SG, Aluminium sulphate, Ferric sulphate, Polyferric sulphate, and Polyacrylamide Zetag 8185 added to diluted manure with 0.5, 1.0, 2.0, and 3.0 % total solids. The samples were then centrifuged and decanted to separate the solid from the liquid fraction. These fractions were then analysed for nitrate, ammonium, and total nitrogen. Except for Tanfloc SG, when the effluent was coagulated and centrifuged, the concentration of nitrate in the clarified liquid reduced compared to when the effluent was only centrifuged. In the same way, centrifugation plus coagulation-flocculation increased the separation of ammonium and total nitrogen in the solid fraction compared to only centrifugation. The exception was Polyacrylamide Zetag 8185, whose inclusion did not increase ammonia removal. In summary, combining centrifugation with coagulation-flocculation processes allows the recovery of a nitrogen-rich solid fraction from diluted manure.

Effect of slurry separation on ammonia and greenhouse gas emissions during slurry storage and field application.

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## Abstract

Slurry management in agriculture causes large emissions of ammonia (NH3) and greenhouse gases (Nielsen, et al. 2019). Ammonia is a precursor for atmospheric nitrous oxide (N2O) and has negative effects on natural ecosystems and human health (Guthrie et al., 2018; Wu et al., 2016). Furthermore, it reduces the fertilizer value of the slurry, so reducing emissions would improve factors across the agri- culture industry.

We investigated whether slurry separation with subsequent drying and pyrolysis of the fiber fraction into biochar for soil incorporation reduces emissions. Emission of NH3, methane (CH4), and N2O from digestate, pig slurry, and their separated liquid fractions was measured during storage (1 $m^3$ tanks) and NH3 emission was measured after field application. Emission was determined using dynamic chambers, with concentrations measured with online cavity ring-down spectrometry.

Preliminary results showed that separation reduced NH3 emissions from field application by 38-75% for digestate and 40-90% for pig slurry. Separation also appeared to affect storage emissions. To reduce field driving costs mixing biochar with the liquid fraction of digestate (pH = 8.0) before application was considered. Adding 5.7% biochar to the liquid fraction showed emissions of ~100% of TAN (resulting pH = 9.2). Addition of 1.1 % biochar had no detectable effect on emission (pH 8.5).

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# Nitrogen rich vegetable residues: lost to the environment or recycled as a resource? A review

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## Abstract

Nitrogen (N) rich vegetable residues are mostly left in fields after harvest and can lead to significant losses of nitrate by leaching and nitrous oxide emission, due to their high water and N contents and fast mineralisation. However, there is a lack of knowledge of the range of N contents and the amount and quality of the residues left in the field of the very diverse group of vegetable crops. The amount and quality are decisive in the evaluation of environmental and climate impact e.g. in climate change models and life cycle analyses. Vegetables are part of the solution to climate change through dietary change towards a more plant-based food consumption. Therefore, it is vital to reduce the N losses from residues in current vegetable production systems. We aimed to 1) compile and analyse data of vegetable residues' N and carbon (C) contents, C/N ratios, and crop and N harvest indices for 72 vegetable crops across 27 countries including own unpublished data; 2) discuss challenges, solutions and research needs to improve methodologies of how to estimate N and C contents and amounts. The amount of residues left in the field varied widely with highest values above 300 kg N $ha^{-1}$. The amount was linked to crop species, field management and other production factors. Solutions for N- efficient management of vegetable residues highlight their potential as a resource by recycling. The study increases data availability and knowledge for evaluation of the environmental and climate impact of vegetable production tied to N rich residues.

## Environmental and economic trade-offs of using organic amendments as partial substitute of synthetic fertiliser

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### Abstract

This study explores the feasibility of substituting synthetic fertilizers with soil organic amendments (OAs), such as compos and manure, focusing on both economic and greenhouse gas (GHG) implications. The analysis encompasses the lifecycle of manure management, including processing (composting vs. stockpiling), transportation, and application in horticultural fields. The OA field application rates were calculated based on the nitrogen supplied by OA. The GHG budget based on directly measured emissions indicates that the application of composted manure, in combination with reduced fertilizer rate, was always superior to stockpiled manures. Compost treatments showed from 9 to 90% less GHG emissions than stockpiled manure treatments. However, higher costs associated with the purchase and transport of composted manure (3 times higher) generated a greater economic burden compared to stockpiled manure and synthetic fertilizer application. However, the plant nutrient replacement value of the OA was considered only for the first year of application and if long term nutrient release from OA is taken into account, additional savings are possible. As the income from soil carbon sequestration initiatives in response to OA application are unlikely to bridge this financial gap, particularly in the short-term, this study proposes that future policy should develop methodologies for avoided GHG emissions from OA application. The combined income from soil carbon sequestration and potentially avoided GHG initiatives could incentivize farmers to adopt OA as a substitute for synthetic fertilizers, thereby promoting more sustainable farming practices.

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D. De Rosa, J. Biala, T.H. Nguyen, E. Mitchell, J. Friedl, C. Scheer, P.R. Grace, D.W. Rowlings Environmental and economic trade-offs of using composted or stockpiled manure as partial substitute for synthetic fertilizer J Environ Qual, 51 (4) (2022), pp. 589-601, 10.1002/jeq2.20255

# Five Success Stories with on Farm Implementation of Nutrient Recovery Technologies in Bavaria (Southern Germany)

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## Abstract

### Introduction

Bavaria's agricultural sector is characterised by small to medium-sized family farms, about half of which are operated as full-time enterprise. The average area under cultivation is just over 30 ha per farm, whilst livestock farming and biogas production (approx. 2500 plants) play an important role for farm income.

In theory, the nutrient balances can be assumed to be equalised, but regional (especially in the southern part of Bavaria) and individual farm nutrient surpluses are frequent. Accordingly, numerous techniques are being used to process slurry and anaerobic digestate. Increasingly, these also include systems for concentrating or recovering nutrients.

### The 5 nutrient recovery technologies

High-performance decanter; products: effluent rich in NH4 and K, solid phase rich in P.

Full-flow drying device; products:  fertilizer pellets for gardening sector, ammoniumsulphate.

Full flow vacuum evaporator, ammonium adsorption, salination; products: ammonium - calcium-granules, digestate concentrate.

Mech. separation, vaccum evaporator, drying device; products: liquid ammonium- sulphate, dried digestate powder for recultivation.

Threestep mech. separation, ammonium adsorption, P-precipitation; products: peat substitute, digestate pellets, AS-Solution, Ca-Phosphate

### Results and conclusions

The presentation outlines the 5 farms with their processing technologies and process chains with reference to their mass and nutrient flows, as well as the energy requirements for electricity and heat, the economic aspects and marketing strategies.

## References

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## Mitigation of greenhouse gas emissions through shade systems and application of biochar and compost in cocoa landscapes in the Semi-deciduous ecological zone of Ghana

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### Abstract

This study aimed to address greenhouse gas emissions in two cocoa landscapes (moist and dry) by examining the impact of shade systems and soil amendments on the release of CO2, CH4, N2O, and overall global warming potential (GWP). The study consisted of two factors: shade systems (no shade and medium shade) and soil amendment (no amendment, mineral fertilizer alone, mineral fertilizer + biochar, ½ mineral fertilizer + compost without rock phosphate, and

½ mineral fertilizer + compost with rock phosphate). The shade system did not significantly influence CO2, CH4, and N2O emissions. Emissions of CO2 were higher in the amended compared to the non-amended plots. Applications of ½ mineral fertilizer + compost increased CH4 production. Greater emissions of N2O were recorded in the amended plots compared to the non-amended plots. Cumulative fluxes of CO2 and CH4 were similar among the amended plots. However, the cumulative flux of N2O was greater in mineral fertilizer alone than in the biochar and compost-treated plots. Soil water and MBC correlated positively with CO2 and CH4 fluxes where soil water accounted for 48 % of the emissions of CH4, and MBC was responsible for 54 and 65 % in the moist and dry eco-zones respectively, of CH4 emissions. Sole mineral fertilizer application had the highest GWP, 14.70 and 13.56 kg CO2 eq $ha^{-1}$ $yr^{-1}$ x $10^5$ in both the moist and dry eco-zone, while the no amendment had the least 8.03 and 8.76 kg CO2 eq $ha^{-1}$ $yr^{-1}$ x $10^5$ in the moist and dry-zones respectively.

Keywords: Agroforestry, Climate-smart fertility, Global Warming Potential, Shade trees, Soil amendment

## 1.5 Session 4 - Incentives for good nitrogen management

### 1.5.1 Keynote: Hans van Grinsven "Lessons from cost-benefit analyses of the nitrogen cascade for policy support from national, to European and global scale"

Hans van Grinsven is Program Manager/Senior Researcher at the Department of Water, Agriculture and Food at Netherlands Environmental Assessment Agency (PBL). His assessment work at PBL and publications cover current practices in agriculture and effects on the environment and options for more efficient and sustainable agriculture and food production in the Netherlands, the EU and globally. Hans works at the science-policy interface on nutrient policies and management, integrated nitrogen assessments and, since 2010, on cost-benefit assessments. Increasingly options go beyond "good practices" and research moves to design and evaluation of transitions towards more nature-inclusive, climate neutral agro-food-systems.

Hans currently is a coordinator and principal investigator for the project "towards the establishment of an International Nitrogen Management System" (INMS 2017-2024) funded by the Global Environment Facility (GEF) through the United Nations Environment Programme (UNEP) and was a coordinator and editor of the European Nitrogen Assessment. He is a member of the Scientific Committee on Nutrient Management Policy (CDM) for the Dutch Ministry of Agriculture.

Hans holds an MSc (1982; Soil chemistry and physics) and PhD (1988; Impact of Acid Atmospheric Deposition on Soils) from Wageningen University.

Lessons from cost-benefit analyses of the nitrogen cascade for policy support from national, to European and global scale

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## Abstract

Cost-benefit analysis (CBA) is an accepted method to inform policy decisions to select interventions that deliver the highest benefits for the target group. The first CBAs for nitrogen related policies (NCBA) were conducted for setting air quality standards for nitrogen oxides in the EU in the late 1990s, and for eutrophication policies in the UK, the Baltic region and the USA early in the 21st century. Central in the air pollution example societal were benefits for increased healthy life expectancy, while, in the eutrophication example, it were loss of value for recreation and waterside property. The first NCBA considering the full N cycle was performed for the European Nitrogen Assessment in 2011, followed by such NCBAs for the USA, the Netherlands and Germany. A first global integrated NCBA will be published this year. In spite of their potential, the use of NCBA for policy is scarce. For example from air pollution NCBAs it was concluded that reducing ammonia emissions delivers far more societal benefits than reducing nitrogen oxides emissions, yet this conclusion has yet to be actioned in current EU policies. Use of integrated NCBAs for international policy bodies (e.g. EU commission and UNEP) needs stimulation. This paper draws lessons from past NCBAs and policy use. We will address uncertainties arising from underlying valuation research (often surveys into preferences) and bias caused by dominance of valuation data from the Global North as possible barriers for policy use. We discuss lack of validation of benefit transfer approaches using gross domestic product and population as scalers both for valuation of N impacts in the Global South and into the future.

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### 1.5.2 Oral presentations

## A cropforecast-based approach for season-specific nitrogen application in winter wheat

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### Abstract

Inadequate nitrogen (N)-fertilisation practices, that fail to consider seasonally variable weather conditions and their impacts on crop yield potential and N-requirements, cause reduced crop N-use efficiency. As a result, both the ecological and economic sustainability of crop production systems are at risk. Forecasts of crop yield and development have thus been promoted as promising means towards more targeted fertilisation practices. The aim of this study was to develop a season-specific crop forecasting approach that allows for a targeted N- application in winter wheat while maintaining farm revenue compared to empirical N-fertilisation practices. Traditionally, such forecasts were based on crop models coupled with climatological records. Evidence that future growing conditions will deviate from historic averages and the improvement of weather forecasting skill give reason to move to crop forecasts that use seasonal weather forecasts instead.

The crop forecasts of this study were generated using the process-based crop model SSM combined with state-of-the-art seasonal ensemble weather forecasts (SEAS5) for the case study region of Eastern Austria. Results from three on-farm experiments showed a reduction in applied N of -23.42% (-43.33 kgN $ha^{-1}$) when implementing a crop forecast-based approach compared to empirical N-application. The monetary incentive was quantified through the economic return to applied N (ERAN). While maintaining revenue from high-quality grain sales, the lower amounts of applied N led to a significant benefit of +30.22% (+2.20 € $kgN^{-1}$) in ERAN. Given the increased frequency of non-average seasons, the value of seasonal crop forecasts for N-application is expected to further increase in the future.

## Enhancing soybean nodulation and yield through additional inoculation with Bradyrhizobium japonicum under field conditions in Denmark

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### Abstract

In Nordic countries, there is a growing interest in boosting local protein production and reducing reliance on imports, with soybean cultivation emerging as a promising option. However, there is a need to better understand how to effectively manage soybean cultivation in regions where there is a lack of Bradyrhizobium strains in soils, given their high capacity for biological nitrogen fixation (BNF). We conducted a study to investigate soybean N2- fixation potential using an inoculant containing the Bradyrhizobium japonicum strain. The study aimed to improve BNF by seed inoculation (the standard method) and applying additional inoculation at the $V_3$ (third node) phenological stage, as an alternative to mineral N fertilizer. A field experiment was conducted during the 2022 and 2023 growing seasons at AU Viborg, Denmark, in plots with no prior soybean cropping history. In treatments without inoculant (control and mineral N fertilizer), no nodules were found. Additional inoculation at the V3 stage compared with the standard method increased nodule number by 44% in 2022 and 41% in 2023. Nodule dry weight increased by 48% in 2022 and 32% in 2023. Yield variations in 2022 ranged from 951 to 1,878 kg ha$^{-1}$, with promising outcomes for additional V3 stage inoculation. However, cold conditions in summer 2023 hindered pod development. Overall, the study enhances soybean cultivation practices for sustainable N management in Denmark, highlighting the importance of Bradyrhizobium inoculation strategies to replace inputs of N-fertilizer. Further research in this area could significantly advance agricultural sustainability.

# Costs and efficiency of environmental technologies as basis for future BAT limits for finisher pigs in Denmark

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## Abstract

An analysis of ammonia reducing technologies and their costs when applied in growing/finisher pig houses has been carried out to establish a basis for future BAT ammonia emissions levels in livestock production in Denmark (Jacobsen and Kai, 2024). The analysis included pen layouts (varying share of slatted floors) and technologies including slurry cooling, air cleaning, slurry acidification, and solid cover of slurry tanks. A total of 270 combinations of the many possible combinations of pen layout combined with one or more environmental technologies were selected for analysis. The analysis covered four farm sizes from 450 to 12.000 animal places.

The analysis indicates that ammonia reducing technologies at farms with growing/finishing pigs in Denmark are more expensive than previously estimated in a similar analysis carried out in 2011 (Miljøstyrelsen, 2011). Only few technologies meet the maximum costs of €1.14 per finisher pig and €13.4 per kg $NH_3$-N which were used to establish BAT emission levels in 2011.

The cheapest technologies and combinations are solid cover slurry tanks and slurry cooling (10W/m$^2$). As expected, implementing the technologies is less expensive on large farms than on small farms. The costs are in several cases twice as large per finisher pig for the smallest farm size compared to the largest farm size.

The analysis helps to get an updated estimation of costs, which can be used both nationally and in the international modelling of costs and measures.

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# Discordance between farmers and scientists – perspectives on nitrogen reduction measure in Denmark.

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## Abstract

Mitigating nitrogen leaching from agricultural land is imperative for enhancing the ecological status of aquatic ecosystems. Incorporating the knowledge and perceptions of farmers regarding the feasibility and effectiveness of implementing nitrogen reduction measures is vital for increasing the adoption rate of such measures and related policies. Concurrently, the insights and perspectives of scientists advising policymakers on the implementation of these measures can facilitate a more comprehensive understanding of the barriers and potential for implementation. In this study, we employ Q methodology to elucidate the opinions of 11 farmers and 14 key scientists involved in providing contractual science policy advice to Danish ministries on nitrogen reduction measures. Results show that across the perspectives of farmers and scientists, four main factors (viewpoints) can be identified: 'Evidence-driven viewpoints', 'On-farm efficiency-driven viewpoints',

'Hydrological and landscape-scale viewpoints', 'Innovation-based viewpoints. From this, we suggest that within the field of nitrogen mitigation and implementation, there is a general broad division and opposing perspectives between scientists and farmers. The evidence presented here shows that scientists' viewpoints do not correspond to the viewpoints of farmers in most cases. Scientists broadly believe that landscape and long-term measures, especially wetlands, are most effective nitrogen measures, according to scientific evidence.

This clashes severely with some farmer participants, who strongly believe that there should be more personal freedom and flexibility to make individual farm level management choices. This is a significant barrier to the uptake of the best possible measures.

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Management, 352, p.119877. https://doi.org/10.1016/j.jenvman.2023.119877

## Advancing nitrogen management in Swiss agriculture: A policy-oriented assessment of manure nitrogen use efficiency

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### Abstract

Since 1999, Swiss farmers need to prove a farm level ecological performance, e.g. by exhibiting a good balance between N input from fertilizers and crop N demand, to be qualified to receive direct payments. However, the current utilized balance system (called Suisse-Balance) provides farmers with a simplified binary outcome (fulfilled or not), posing challenges for assessment of manure nitrogen (N) management performance.

The primary objective of this research is to propose a change in the Suisse-Balance calculation structure, to display tangible indicators, that can be communicated to farmers and policy makers. Additionally, we quantify the farm N loss reduction potential based on defined scenarios representing a gradient of manure management optimization strategies (no measures implemented to most technical measures implemented) to map the effect of individual measures on the entire farming system.

We used the SAGE (Swiss Ammonia and Greenhouse gas Emission) model to quantify the N flows along the manure cascade of a dataset of about 300 mixed Swiss farms of the Swiss agri-environmental data network (Gilgen et al. 2023). On average, a methodological change would result in an approximative increase of 4% in manure N utilization efficiency. An implementation of most technical measure to optimize manure N management results in an increase of 20% manure N utilization efficiency.

A model-based manure cascade calculation reflecting the reality of on farm N flows can increase transparency and robustness for decision making on the farm and at the policy level, and help truly decreasing N losses to meet national environmental targets.

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## Assessing Policy-Induced Adaption of Crop Choices: A Case Study for the German Implementation of the EU Nitrates Directive

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### Abstract

The German implementation of the EU Nitrates Directive underwent fundamental changes over the last years. So-called red areas, where high nitrate concentration in groundwater bodies is found, were introduced alongside additional restrictions for fertilizing activities. Farmers are likely reacting by changing management such as adapting fertilizer amounts or crop rotations. Knowledge on such responses is valuable to capture unintended environmental consequences and estimate economic impacts, especially as the red areas have been strongly enlarged in 2022.

We contribute to the debate by assessing if farmers adapt their short-term crop choices in red areas, using a Bayesian probabilistic programming approach. More specifically, we apply a multi-level model which allows for individual field-level intercepts (similar to a fixed-effects model) while estimating an adaptive prior for those intercepts at the regional level (NUTS3). We focus on the German Federal state of North Rhine-Westphalia and use spatial explicit field data from the Integrated Administration and Control System (IACS).

Our first results indicate that farmers' short-term reactions to stricter regulations is overall modest but that there is a substantial regional heterogeneity in how farmers respond to the policy. In the future, the developed method can be used to assess the impact of other policies on crop choices as well as to link the implementation of the EU Nitrates Directive to changes in groundwater quality.

## Climate change impact on hydrological and nitrogen cycling in an intensive agricultural watersheds in Brittany, western France

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### Abstract

The objective of our study is to assess the climate change impact on hydrological and nitrogen cycling in intensive agricultural watersheds in Brittany, western France. The Quillimadec (89 $km^2$) and Semnon (267 $km^2$) watersheds were selected in this region for their contrasting pedoclimatic conditions and agricultural production. First, we calibrated and validated the agro-hydrological, TNT2 model (Beaujouan et al., 2002), for the water discharge, nitrate concentration and loads at the outlet of both watersheds. Then, we simulated twelve combinations of global climate models and regional climate models under the RCP8.5 emission scenario in each watershed from 2023 to 2053. The climate data from this selection are already biased and this selection captures the divergence in climate data. In addition, we considered two agricultural scenarios: the adoption of agroecological practices and the continuation of the current agricultural intensification. The increasing atmospheric CO2 levels is also considered in our simulations.

The results of this study are currently being processed, and we will present our findings at congress.

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## Impact of changing agricultural management on the exceedance of empirical critical loads of nitrogen in terrestrial habitats of southwestern Europe

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### Keywords

Ammonia emissions, N deposition, critical loads, biodiversity, Mediterranean region

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### Abstract

Nitrogen deposition into terrestrial ecosystems is an environmental threat derived from the anthropogenic emission of nitrogen (N) pollutants to the atmosphere. One of the major sources of ammonia are the agricultural activities. This study reports on the development and use of an integrated modeling system to evaluate some key mitigation measures focusing on N management in agricultural land in Portugal, Spain, and southern France (SUDOE territory). Emissions of ammonia from applied manure and synthetic fertilizers were estimated using the MANNER model, and the chemical transport model CHIMERE was used for N deposition simulations. Two scenarios were tested: the current situation and a scenario of ammonia emission mitigation that included several mitigation options for crop production that could be implemented in a near future (mainly, remotion of synthetic urea fertilization, exclusively use of CAN-type fertilizers and fast incorporation of manure after application). According to the models, the measures applied in the later scenario caused a 38% reduction of ammonia emissions in the SUDOE territory and a subsequent 20% decrease in atmospheric deposition of reactive N. A risk assessment of N deposition effects in terrestrial ecosystems was performed by using the critical load methodology of the Air Convention (UNECE). The Mitigation scenario produced a 43% decrease in the area at risk of N deposition effects for the whole SUDOE territory. Atlantic and Alpine biogeographical regions experienced a greater percentage of evaluated areas at risk than the Mediterranean region, and a lower efficiency of the Mitigation scenario in reducing the area at risk.

## NUTRI-CHECK NET: Developing a Measure-to-Manage approach for Crop Nutrition across Europe.

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### Abstract

Europe is facing a significant challenge to increase crop productivity whilst reducing dependency on synthetic fertilisers and minimising nutrient losses. Fundamentally, all crop nutrition challenges are simple and similar: to judge shortfalls between crop demands and soil supplies of all nutrients and match these with additions of sufficient crop available nutrients. Multiple and diverse tools are already available to support these challenges. However, despite multiple public investments in defining and disseminating tools and best practices (BP) for crop nutrition management, BP vary between nations, have only minority adoption, and generally omit on-farm assessments of final success.

NUTRI-CHECK NET is a Europe-wide project which is addressing crop nutrition decision making on arable farms over three years to 2025, establishing a self-sustaining, multi-actor, Thematic Network to build farm-level adoption of best field-specific crop nutrition management practices. An inventory of existing tools has been prepared by partners in nine countries, and 26 Crop Nutrition Clubs (each of 5- 20 farmers and advisors) are choosing tools from this 'toolbox' and evaluating how well these contribute towards defining the 'Requirements', making 'Refinements' and deducing 'Outcomes' of each crop's nutrition through each season. Farmers will measure outcomes by analysing grain or tuber nutrient contents at harvest and crop yields. Farmers and experts will evaluate the pertinence, ease of use, trustworthiness, costs, and benefits of using each tool. Initial and final evaluations will be shared across the Network to define BP. Meanwhile, findings and conclusions are being demonstrated and disseminated across Europe, supported by an online platform.

## Tackling the Dutch nitrogen crisis: Policies and Challenges in Agricultural Nitrogen Reduction

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### Abstract

In 2019, the Dutch Council of State determined that the policy approach to prevent harmful effects of nitrogen emissions on Natura 2000 areas had failed and was in violation of the EU Habitat directive. As a result, authorization of permits for new nitrogen-emitting activities almost came to a standstill, giving rise to the Dutch 'nitrogen crisis'. Shortly after, the government enacted a new law mandating that by 2035, at least 74% of the protected Nature 2000 area should not exceed critical nitrogen loads (whereas this was 28% in 2021). To achieve this, the newly established Dutch Ministry for Nature and Nitrogen Policy announced several measures to 'drastically cut nitrogen emissions' within the next decade. Many of these measures focus on the agriculture sector, which contributed 46% to nitrogen deposition on Dutch nature areas in 2021. In this presentation, we provide an overview of current and considered policies for mitigating agricultural ammonia emissions in the Netherlands. These measures encompass buyout schemes to decrease livestock numbers, the implementation of emission standards, subsidies for low-emission housing systems, restrictions on livestock density, and the reduction of crude protein content in animal feed. We discuss the results of recent evaluations of Dutch nitrogen policies (PBL et al., 2022, 2024), which indicate that with current measures, the government's nitrogen targets are far out of reach. We also address the repercussions of the discontinuation of the derogation for the Nitrates Directive in 2025 that allowed dairy farmers to utilize more than 170 kg of nitrogen per hectare from manure.

Finally, we reflect on the role of nitrogen within the broader set of challenges facing the Dutch agricultural sector, such as reducing greenhouse gas emissions and improving water quality.

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# MIXED farming, agroforestry systems and landscape scale guidance for integrated nitrogen management

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## Abstract

The MIXED-project.eu explores benefits of Mixed Farming and Agroforestry Systems (MiFAS) to climate, environment and society, including policies, incentives and governance strategies to promote such systems development across Europe. The area has attracted an increased attention in scientific literature[1]. A hypothesis is that MiFAS simultaneously can lead to more efficient and resilient production systems. This paper presents examples to support this, including in relation to nitrogen management and efficiency at the landscape scale, and for the related farming systems and value chains.

Networks of organic and conventional farmers are the backbone of the project, and a data collection across Europe, to create the opportunity for farmers and researchers to learn from each other, and how best to facilitate a wider take-up of MiFAS. Results include i) examples on better use of resources through collaboration and diversified production (crops, trees, animals), ii) use of crops, grasslands and woody vegetation to feed and shelter animals and fertilise fields with manure, as well as provide benefits such as carbon sequestration and improved biodiversity, or iii) diversified production systems to enhance resilience to change (e.g. climate changes or different types of economic chocks), and to support a more circular use of resources, thereby gaining a better overall economic as well as environmental efficiency and nitrogen balance. The effects are discussed in context of the recently reviewed landscape scale measures and guidance for integrated nitrogen management[2] and potentials to take advantage of heterogeneity and diversity including MiFAS in the development of more sustainable agricultural landscapes.

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## Impact of nitrogen management on crop performance, agronomic nitrogen use efficiency, soil health and greenhouse gas emissions in direct seeded rice of central Vietnam.

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### Abstract

Growing rice by direct seeding method is getting popular in many parts of Asia and challenged by low nitrogen use efficiency subjected to greenhouse gas emissions (GHGs) (Jiang et al., 2019). Impact of nitrogen rates (0, 40, 80, 120 kg ha-1) and fertilizer types (urea, ammonium chloride and calcium nitrate) was assessed on crop performance, dry matter production, CH4 and N2O emissions, profitability and water productivity for direct seeded rice grown in spring and summer seasons compared to continuous flooding. Application of 120 kg N ha-1 using urea and ammonium chloride produced highest productive tillers, dry matter and grain yield in both growing seasons with no significant difference than 80 kg N ha-1 for grain yield. Highest grain yield for 80 kg N ha-1 was associated with increased panicle numbers, filled spikelets and 1000- seed weight (Rehman et al., 2023). Organic matter, nitrogen contents and available phosphorus also improved for 80 or 120 kg N ha-1 for each source. Mean CH4 and N2O emissions decreased by 33% and 20% for urea than ammonium chloride at 120 kg N ha-1 in both seasons. Maximum agronomic N use efficiency was found for 80 kg N ha-1 urea that ranged 20.8 to 22.5 kg grain yield kg N-1 in both growing seasons, followed by ammonium chloride. Thus, optimizing N fertilizer using 80 kg N ha-1 urea can be economically viable to improve agronomic nitrogen use efficiency, grain yield, soil health and mitigate CH4 and N2O emissions under direct seeded rice cultivation in Central Vietnam.

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Soil carbon and nitrogen under compositionally different pasture systems

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## Abstract

Dairy pastures in southern Australia are traditionally heavily fertilized perennial ryegrass dominant. These pastures are highly productive when nutrients and water are non-limiting. Management of pastures on the growing season shoulders in rainfed systems is challenging, more so with increasingly variable climate. Increasing interest in multispecies pastures, comprised of grasses, legumes and herbs, is occurring in Australia as a consequence of changing climate, cost of summer feed, interest in soil health, and a desire for less reliance on synthetic fertiliser, particularly nitrogen (N). Another incentive for change is the potential for deep profile carbon (C) sequestration under multispecies pastures (Cummins et al. 2021) and a more resilient system. Our research investigated the soil profile C and N content to 60 cm depth under monoculture and multispecies pastures across eleven commercial dairy farms in three different climatic regions of southeastern Australia, to determine the potential for deep C storage and the long-term cycling of N. Our results indicated that greater C and N (total and labile) storage occurred in the topsoil under both pasture types across all sites, that the potential for C storage in the topsoil was influenced more by climate than pasture type, and that region (climate) significantly affected the C and N in the soil profile. Evidence of plant roots accessing lower depths was seen in the soil moisture profiles, but this had not translated into changes in soil C and N which may be a consequence of the limited timeframe (< 5-10 years) since pasture establishment.

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## 1.6 Session 5 - Food systems

### 1.6.1 Keynote: Josette A. Garnier "Towards food self-sufficiency of territorial agri-food systems: different degrees in N circularity"

Josette A. Garnier is a Research Director at the National Center of Scientific Research (CNRS) in the field of Biogeochemistry of River Basins. Her main interest lie within the land-to-sea continuums, water-agri-food systems and socio-ecological metabolism studies. She is currently working on the biogeochemical functioning of large watersheds, including the human activities in their basin (specifically, domestic waste waters and agriculture). Coupled models that she contributes to elaborate, allow to explore scenarios of changes in agricultural practices and systems, and to quantify the environmental impacts. This approach is currently used at various spatial scales (small territories, countries and European scales). Long term studies also helps determining past trajectories, useful for co-construction of scenarios.

Towards food self-sufficiency of territorial agri-food systems:

different degrees in N circularity

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Abstract

Describing Nitrogen flows through territorial agri-food systems, from agricultural lands, livestock and consumers allows exploring the issue of N-circularity in relation with N-inputs (as fertilizers, food and feed), N-exports and N-losses.

The GRAFS approach has been developed at the scale of Europe divided into 127 regions, providing a detailed description of the current degree of specialization and opening of the agri-food system (Billen et al., 2024). Two alternative prospective scenarios have been designed, differing in their degree of N-circularity but using the same population projection. The first one, "Agroecology", assumes (i) the generalization to all current land areas of crop rotations in use in organic farming; (ii) the reconnection of cropping and livestock systems with no feed import and livestock numbers adjusted to feed resources; (iii) a decrease to 30% animal protein in the human diet; (iv) a 25% reuse of human excreta. "Radical sobriety" calls

for a complete overhaul of lifestyles (Barles et al., 2023). Population is redistributed from high-density towns to rural areas with land used changed, maintaining or increasing grassland areas, increasing forest by 15%. A further decrease to 20% animal protein in the diet is considered and 70% of human excreta is recycled to agriculture. Livestock numbers are adjusted to food, feed and animal traction requirements. Excedentary land areas are set aside for reforestation and rewilding, which promotes biodiversity.

Both scenarios can feed the European population, and export some cereal surpluses. They however greatly differs in terms of environmental burdens and N-losses (Garnier et al., 2023).

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### 1.6.2 Oral presentations

# Quantifying the impact of an abrupt reduction in mineral nitrogen fertilization on crop yield in the European Union

Federica Pacifico [a], Giulia Ronchetti [a], Maurits van den Berg [a], Frank Dentener [a], Marijn van der Velde [a], Emanuele Lugato [a]

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## Abstract

Fertilizer prices soared in 2021-2022, and remained at historical high levels in 2023, raising concerns for European and global food security. In our study, we use the DayCent biogeochemical process-based model to quantify an abrupt reduction of mineral N fertilization on the major crops of the European Union (EU). First, we evaluate major crop yields (soft wheat, barley, grain maize and rapeseed) simulated with DayCent against subnational yield data reported by Eurostat and National Statistical Institutes in the EU. Then, we simulate three different scenarios where mineral N fertilization across the EU is abruptly reduced by, respectively, 5, 15 and 25%, and compare yields to the projected baseline for contemporary conditions (2019-2022).

The model shows a reduction in yield per crop, at the EU level, up to 2.1, 6.4 and 11.2% with the 5, 15 and 25% reduction scenario, respectively. Different crops show different percentage reduction in yield following a reduction in mineral N fertilization, showing a legacy effect over the years and depending on the availability of organic fertilizer. The strongest relative yield reduction occurs for soft wheat for all three scenarios. Even with 25% drop in mineral N fertilization, maize yield in the Netherlands, Belgium and Denmark is not significantly reduced, because of the high N surplus and large share of organic fertilization in these countries.

This process-based modelling study provides spatially explicit, high resolution information on the response of crop yields to N fertilizer input reductions, helping policy-makers in decision-making on food security and environmentally-friendly food systems.

## Food self-sufficiency in small islands: an approach based on nitrogen flows

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### Abstract

After decades of agricultural specialization and opening to international markets, national or territorial food security, self-sufficiency and sovereignty are coming back as major political issues, although these concepts lack rigorous definition and precise indicators (FAO, 1999; Clapp, 2017). Instead, we propose to define import dependency as the amount of food, feed and fertilizers needed for providing food to the human population. The case of Reunion Island, a small volcanic island 680 km east of Madagascar, specialized into sugarcane cultivation, is chosen to illustrate this general concept.

The application of the previously developed GRAFS model (Billen et al, 2024), allowing consistent balances to be established using nitrogen (N) as a common metric for all crops and foodstuffs, shows that in Reunion Island, the supply of one tonne of N as food to the population requires the total import of 2.7 tonnes of N as food (67% of its food supply), feed (54% of all feed) and fertilizers (57% of all fertilizing N inputs to agricultural soils).

The model also demonstrates that the simultaneous operation of three levers of change would make it possible to reach self-sufficiency in terms of food, feed, and fertilizer: (1) the generalization of agro-ecological crop rotations alternating grain and forage legumes, cereal, and other food crops; (2) the reconnection of livestock with crop farming and a better recycling of animal and human excreta; (3) a drastic reduction of animal-based food in the Reunionese diet. Sugarcane areas should be reduced to 15–25% of their current value.

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## Key Causal Predictors of Theoretical Maximum Yields across Europe

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### Abstract

The Generalized Representation of Agro-Food Systems (GRAFS, Billen et al. 2014) model can be used to describe nitrogen, phosphorus and carbon flows in agri-food systems. This approach is based on an empirical relationship that has been validated in a wide range of European agronomic systems (Billen et al. 2024). It establishes a link between crop rotation-scale nitrogen yields (Y) and total nitrogen inputs (F) from synthetic fertilizers, manure, biological fixation, and atmospheric deposition, following a hyperbolic shape $Y = F \times Ymax / (F + Ymax)$, with a single parameter Ymax representing the theoretical maximum yield (Lassaletta et al. 2014).

Here, building on this framework, we aim to clarify the role of agro-pedo-climatic variables as predictors in the spatial variability of Ymax value on a European sub-national scale. We fit a statistical model predicting the European spatial distribution of Ymax and showed that climatic predictors related to water balance, solar radiative flux, and temperature clearly act as key limiting factors on Ymax in the southern and northern extremes of Europe. However, in mid-latitudes of temperate Europe, the predictors are more numerous and related to soil characteristics, agronomic practices, and the frequency and intensity of extreme weather events. These findings, due to the strong climatic gradient across Europe, will be useful to estimate likely climate-driven development of Ymax values for each European region in the future. This study therefore lays the groundwork to enhance the predictive capacity of the GRAFS model within the context of climate change and changing agricultural practices and land use.

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## Development and evaluation of agricultural nitrogen budgets in Denmark and Sweden

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### Abstract

Agriculture plays a significant role in surpassing the nitrogen (N) planetary limits. Ensuring crop productivity while maintaining high N use efficiency (i.e., the ratio between N outputs and inputs) with low N environmental emissions poses a major challenge for food production. This challenge is particularly pronounced in North European countries, known for their highly intensive agricultural practices. We quantify the N flows in agricultural inputs and outputs at subnational level (NUTS 2) in Denmark and Sweden from 2011 to 2020. Moreover, we estimate the nitrous oxide ($N_2O$) emissions using a Tier 2 approach. We found that the crop N use efficiency was 63 and 78 % for Denmark and Sweden, while the livestock N use efficiency was 16 and 21 %. There are several reasons for these differences, likely mainly differences in crop and livestock production composition in the two countries. The primary source of N fertilizer was organic in Denmark (215 kt N $y^{-1}$, 65 kg N $ha^{-1}$ $y^{-1}$) and synthetic in Sweden (162 kt N $y^{-1}$, 59 kg N $ha^{-1}$ $y^{-1}$). The $N_2O$-N emissions averaged 5.7 kt $y^{-1}$ for Denmark, and the emissions from organic fertilizer application (2.2 kt $N_2O$-N $y^{-1}$) were the main contributor. For Sweden, $N_2O$-N emissions averaged 3.9 kt $y^{-1}$, with synthetic N fertilizer (1.6 kt $N_2O$-N $y^{-1}$) as the main contributor. This research provides quantitative policy-relevant information on environmental metrics for sustainable N management, land use, and agricultural production, which is urgently needed to transition towards more sustainable agricultural systems in Denmark and Sweden.

# The Nitrogen Footprint of Ukraine: room for reduction through changing personal diet

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## Abstract

Reactive nitrogen (N) losses from agriculture, energy, and transportation threaten the environment, causing eutrophication, acidification, pollution, biodiversity loss, health risks, and greenhouse gas emissions (Galloway et al., 2021). The Nitrogen Footprint concept tracks potential N losses along the production-consumption chain (Leach et al., 2012).

An individual N Footprint (INF) study in Ukraine pinpointed key factors: food production, consumption habits, sewage collection and waste water treatment systems (Medinets et al., 2024). Challenges include data gaps, soil nitrogen depletion and mismanagement of manure waste. Ukraine's INF (22.1 kg N $yr^{-1}$ in 2017) matched Western Europe but lagged behind the US and Australia. Yet, ample opportunities for reduction persist through promoting healthier and more sustainable dietary choices.

Various dietary scenarios, including adjusting total protein intake to that recommended by the WHO and national dietary guidance, with or without changing the diet, demonstrated potential reductions: omnivorous (22%), reduced red meat consumption (33%), elimination of red meat (44%), halving meat consumption (45%), adopting a vegetarian diet (49%) and embracing a vegan diet (69%). Implementing proper manure management and improved wastewater treatment could yield even greater reductions in the 'actual' INF.

To aid in estimating and tracking footprints, a multilingual online N-calculator, including Ukrainian, has been launched (https://n-print.org).

For Ukraine's post-war reconstruction, sustained support, capital investments, legislative improvements, and regulatory frameworks are vital for reducing INF. This entails enhancing nitrogen use efficiency in agriculture, adopting efficient manure management, upgrading wastewater treatment, promoting renewable energy, bolstering infrastructure and raising public awareness of environmental sustainability.

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Myths and facts about plant and animal protein in human nutrition

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## Abstract

The contribution of different protein sources to human nutrition is often treated in food systems research as a one-dimensional question of total nitrogen or protein intake. In established nutrition science, however, dietary protein is considered as individual amino acids, most importantly the nine indispensable amino acids (IAAs) which the human body cannot synthesize and which therefore must be supplied through the diet.

Some voices rightly caution against treating all dietary proteins as equal, since different plant and animal food categories have different composition of IAAs. This is sometimes exaggerated or misunderstood as plant protein completely lacking some IAAs, while the fact is merely that most plants have IAAs in proportions suboptimal for human nutrition. As a result of myths and misconceptions, there is confusion and sometimes heated debate over the contribution of different foods to human protein nutrition.

Here, we present a practical approach to quantifying human protein nutrition in terms of both total protein and individual IAAs, using and the Digestible Indispensable Amino Acid Score (DIAAS) as recommended by FAO (2013). An open-source calculation tool ready for integration in food systems research is presented and demonstrated. A novel database of digestibility data accounting for effects of cooking is included. The nutritional value of adding animal protein to frugal diets based on mainly plant-based staple foods is quantified. Research needs are highlighted. This presentation and the calculation tool will help food systems researchers understand and apply established nutrition science to questions around food system sustainability and human nutrition.

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## Consumption-based assessments of nitrogen losses from the global food system

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### Abstract

The modern global food system is the largest driver of nitrogen imbalances across the world. These problems are exacerbated by excessive and resource-intensive food demand prone to large amounts of loss and waste throughout the food system. Increasing international trade is shifting the burden and upstream nitrogen demand and downstream eutrophication impacts beyond national borders and moving beyond the safe regional boundaries for their presence in the environment. To better understand drivers and solutions to close nitrogen loops, we use the global food input-output model FABIO, which monitors the movement of biomass and the land utilized across global supply chains, encompassing 191 countries, and 130 agricultural and food products. We couple FABIO to nitrogen crop demand, livestock manure management systems, and agricultural surpluses to assess the consumption-based drivers for nitrogen emissions stemming from the agricultural system. A substantial amount of nitrogen these losses can be attributed to traded commodities especially toward high- income nations. We provide scenarios for various dietary changes that can help ameliorate global nitrogen losses, focusing in areas sensitive to terrestrial and aquatic eutrophication and acidification.

## Emergy approach to the sustainable use of ecosystems towards better soil and nitrogen management

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### Abstract

Montado systems are facing decline, largely attributed to climate change and inadequate management practices. Grazing pressure emerges as a critical factor contributing to this decline, with overgrazing often linked to stocking rates and pasture biomass yield. While livestock density plays a role, it is not the sole determinant. Optimal stocking rates for montados typically range from 0.18 to 0.60 livestock units per hectare (Rodrigues,A. et al. 2019), but effective grazing management, which allows for vegetation recovery, and pasture type are equally vital considerations. Biodiverse permanent pastures have gained popularity for their ability to enhance biomass yield and reinforce soil functions. Our hypothesis posits that increased nitrogen use efficiency in these systems can lead to a reduced nitrogen production footprint. Thus, our study aims to comprehensively evaluate the management practices of montado systems with biodiverse pastures compared to those with natural pastures. To achieve this, we employed an emergy assessment (Ulgiati, S. et al. 1995) to gain insights into the resource management dynamics. Additionally, we calculated the nitrogen footprint of production using the nitrogen footprint calculator (Leach, A. et al. 2012) methodology, to provide valuable information to end consumers regarding the environmental impact of the products.

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### Aknowledgements

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## The role of nitrogen in the food systems and bioeconomy transformation

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### Abstract

Nitrogen is a key nutrient for food production and essential element for humans to build structural and functional proteins and nucleic acids. Food systems are key drivers for nitrogen losses. Therefore, when attempting to reduce nitrogen wastes, a coherent approach to the food systems is needed. The EU Farm to Fork and Biodiversity Strategies and the Colombo Declaration on Sustainable Nitrogen Management, have set policy targets for nitrogen waste reduction by 50%. How can those urgent targets be realistically met? What technologies and policy design are needed? These questions have been investigated in the 2nd European Nitrogen Assessment Special Report "Appetite for Change. Food system options for nitrogen, environment & health". Findings show that targets can be met by combining farm-level technical measures, improvements in sewage systems, and reduction of food waste, with dietary changes. Semi-quantitative assessment of the societal costs revealed that measures at moderate ambitions yields highest societal benefit. Accordingly, meat and dairy consumption should – at aggregate level – be reduced by 50% (demitarian diet). However, such a policy design is conditioned by directionality, coordination and coherence across policy sectors to enable joint action, including financial, informative, regulatory, and behavioral policies. To be successful though, food system policies need to be embedded inbroader policy frameworks such as the 'Bioeconomy Strategy'. While measures to reduce nitrogen wastes in food system are essential in contributing in the transition to sustainable and circular bioeconomies, bio-based value chains on the other hand provide opportunities for diversification of income streams for primary producers.

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## Côte d'Ivoire's agro-food systems at a crossroads: Nitrogen fertilization and crop production on a regional scale

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### Abstract

In Ivory Coast staple and cash crop productions play a key role for food security and economic development but are threatened by decreasing cash crop yield and increasing dependence on imported staple food. In this context, it is key to understand the trade-offs between fertilization, crop yields, livestock density, staple crop sufficiency and cash crop export. To that end, we applied the Generalized Representation of Agro-Food Systems (GRAFS, Le Noë et al, 2017) at the regional level in Ivory Coast by making use of the most recent census data (FAO and Ivorian Ministry )for describing nitrogen (N) fluxes in territorial agricultural systems. Our preliminary results reveal important regional specialization, particularly for cash crops, and strong potential for self-sufficiency in staple crops in most regions except Abidjan. We found, however, that N fertility is threatened, with export through harvest surpassing soil N inputs in cropping systems, while important N loads are found in the fast-growing Abidjan region. However, the current GRAFS approach overlooked the role of long-fallow in soil N inputs. Therefore, we propose a new development of the GRAFS model to include long-fallow in crop rotations. Assuming a rotation of 3 to 6 years fallow followed by 2 to 3 years staple cropping (N'Goran et al., 2007) would allow sufficient N inputs, but a decrease in fallow duration would become unsustainable. In perennial cash crops, considering 15 to 20 years fallow followed by 10 to 15 years continuous cultivation (Ruf et al 2020) would already threaten sustainability.

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## 1.7 Session 6 - Livestock in agricultural systems from a nitrogen perspective

### 1.7.1 Keynote: Cecile de Klein "The role of nitrogen management in lowering nitrogen and greenhouse gas losses from grazed dairy systems"

Cecile de Klein is an internationally recognised scientist in environmental management of agricultural systems, with focus on nitrogen cycling and greenhouse gas emissions from grazed livestock systems. She is a Principal Scientist with AgResearch and a Principal Investigator of the New Zealand Agricultural Greenhouse Gas Research Centre where she leads the nitrous oxide research programme. Cecile was part of the International Nitrogen Management System project team that developed guidance on farm N budgets and N performance indicators. She works closely with the agricultural sector and policy makers in New Zealand to help develop tools for on-farm management of nitrogen flows and GHG emissions, and to improve national GHG accounting.

The role of nitrogen management in lowering nitrogen and greenhouse gas losses from grazed dairy systems

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Abstract

Grazed livestock systems are the dominant agricultural system in New Zealand. In recent decades NZ dairy systems have seen significant growth, which has resulted in pressures on water quality and increases in greenhouse gas (GHG) emissions. Nitrogen (N) management options play an important role in minimizing these environmental impacts, whilst achieving economically viable farm systems. In this paper we will summarize the results and key findings of dairy systems research conducted in New Zealand over the past two decades. We will distill key principles on the role of N management for lowering GHG emissions and N losses to water and, where possible, farm operating profit. The potential trade-offs and co-benefits of these changes will also be discussed. We will focus on impacts of singular as well as stacked mitigation and management options, including, but not limited to: improving animal performance through better feeding and using cows with higher genetic merit; lowering dietary N concentration; using multiple species swards; introducing biological and chemical

nitrification inhibition; and restricting pasture grazing during autumn and winter (e.g., Clark et al. 2020; de Klein et al. 2020; Monaghan et al. 2021, and unpublished data). We will also discuss the impact of land-use diversification within dairy farms for reducing N losses and off-setting GHG emissions. Some apparent contradictions between proposed N management options for grazed grass/clover-based dairy systems versus those for predominantly housed dairy systems will also be explored.

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### 1.7.2 Oral presentations

## Developing Sustainable Agricultural Budget Using System Dynamics Approach: Türkiye Case

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### Abstract

One of the main questions today is to identify the bi-directional relationship between climate change and the anthropogenic nitrogen budget (Gruber and Galloway, 2008; De Vries et al., 2011). Agricultural activities (crop production and livestock breeding) are the main components of human-induced reactive nitrogen (Nr) creation. Regional programs are needed to determine Nr concentrations and to evaluate their mobility in ecosystems for sustainable regional nitrogen management (Sutton et al., 2013). A dynamic N-budget model is developed for agricultural soils based on crop production (including 183 types of industrial crops and plants) and livestock production (16 types of animals). Nr emissions (direct $N_2O$-N emissions, $N_2$-N emissions, $NH_3$-N emissions, $NO_x$-N emissions, and N loss due to leach/runoff) due to synthetic fertilizer use, different manure management technologies for different animal types, as well as Nr emissions occurring on pasture, range, and paddock due to grazing of animals, are determined. The model is simulated between the years 2000 and 2016. The results showed that 42% of the nitrogen in total manure (during grazing and manure management) and 13.5% of the nitrogen in synthetic fertilizer is lost to the ecosystem before plant uptake, and 6.6 million tons of Nr are accumulated in the agricultural soils during the simulation period. Net annual N surplus (including atmospheric deposition) fluctuated between 4.1 (in 2011) and 22.2 kg/ha (in 2016). The model is flexible and can be used to evaluate the impact of different scenarios in other countries.

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## Distribution of Nitrogen and Ammonia among livestock farms in Brittany (France)

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### Abstract

Brittany is one of the European regions with a high nitrogen pressure and ammonia emissions due to manure management from livestock (EEA, 2022). To impose or finance the best techniques, decision-makers need data on the distribution of these nitrogen emissions between the different farmers and forms (solid manure, slurry, droppings) and places (housing, pasture, outdoor run) the manure is produced. With a specific set of data (Loyon, 2022), the contribution of the different breeding systems (cattle, pigs, poultry and mixed animals) to the nitrogen pressure and ammonia emissions in 2022 is calculated. The total organic nitrogen produced in 2022 (179.8 kt N) is distributed between building (70.3%) and grazing (29.7%). The building nitrogen is in solid manure (51.7%), in the form of slurry (44.4%) and in the form of droppings (3.9%). In terms of animals, the main contributor is the cattle herd (109.3 kt N, 20.7 kt N-NH3), followed by the pig herd (45.3 kt N, 19.9 kt N-NH3) and the poultry herd (23.5 kt N, 13.2 kt N-NH3). Farms are mostly specialized in cattle, pigs, or poultry (77.4% of total farms, 75.8% of total organic N). More figures allow the distribution of the N and NH3 according to the farm size (LSU). These results indicate that some of the nitrogen and ammonia are more difficult to control by manure treatment techniques or air scrubbers. These results also indicate the better nitrogen emissions places to target and the number of farmers who can be target to reduce nitrogen subsequently.

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# Uncertainties in manure and fertilizer application and $NH_3$ and $N_2O$ emissions from agriculture in the Netherlands across different spatial scales

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## Abstract

National emissions of $NH_3$ and $N_2O$ from agriculture are commonly quantified using agro-environmental models. Activity data such as livestock numbers, nutrient excretion rates, grazing hours, fertilizer use, emission factors and manure transport statistics serve as model inputs, but are known to come with uncertainties which can affect model accuracy of emission estimates across different scales (e.g. local, regional, national). Currently, insights are limited into how uncertainties of model input parameters (MIPs) propagate through the uncertainties in the modelled emissions, especially at the more local levels in the neighborhood of nitrogen sensitive nature areas.

In this study, we estimate the uncertainties of livestock manure application and emissions of $NH_3$ and $N_2O$ on a local, regional and national scale for the Netherlands. To do so, we apply a Monte Carlo uncertainty propagation analysis (UPA) to an agro-environmental model called INITIATOR (De Vries et al., 2023). By using UPA, we calculate how uncertainties for a large set of MIP's, e.g. livestock numbers, nutrient excretion rates, emission factors or fertilizer use propagate through uncertainties in model outputs across the different spatial scales (500m grid, regional, national).

Topics that will be addressed in the results and discussion section include the effect of spatial scale on uncertainties, the contribution of different MIP groups to the overall uncertainty, and the evaluation of model sensitivity related to pre-defined probability distributions and correlation values. In the discussion, we will also address how our findings can be utilized for reducing the uncertainty in emission calculations in the Netherlands.

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## Mobile hen houses without floor panel and nitrogen leaching - a bottomless pit?

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### Abstract

Mobile housing systems for chicken can be shifted thereby providing the animals with new pasture which might help reduce helminth and nitrogen burdens (Maurer et al. 2013; Trei et al. 2015). However, mobility depends on size, weight and structure of the mobile house as well as soil conditions and thus it may take less than one or even up to 20 hours to shift the stable (Trei et al., 2015). This affects shifting frequency and standing duration. Some mobile houses are built without a floor panel. Thus the feces dropped within the barn accumulate on the ground beneath. We measured the content of mineral nitrogen (0-90 cm) beneath mobile houses that have no built in floor panel. Farm A had sandy soil, held 1.000 animals and used straw as litter which was removed as manure after shifting the barn to another site. Samples were taken for 3 years before and after standing durations of 24 and 26 weeks. Results showed an increase from 14 g $N_{min}$ /m² before up to 102 g $N_{min}$ /m² after the standing duration, despite manure removal. Farm B held 1.650 animals on a loamy soil, accumulated feces were removed after shifting the barn. Samples were taken continuously for 3 years after a standing duration of 29 weeks. Mineral nitrogen contents ranged between 240 and 695 g/m² throughout the survey with a mean of 379 g/m² (±114). To prevent high accumulation of nutrients in the soil mobile houses need to have an underfloor protection which at the same time doesn't impede mobility.

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## Grazing dominantly regulates top soil organic nitrogen and carbon stocks in grasslands

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### Abstract

The Biodiversity Exploratories (BEs) have collected detailed data on land use intensity (LUI) measured by three components grazing, mowing and fertilization as well as data on climate, plant and microbial biodiversity for the past 17 years in three areas across Germany.

Since these factors alongside physicochemical processes interactively drive soil nitrogen (SON) and carbon (SOC) cycling and storage, the BEs offer a unique opportunity to gain a mechanistic, process-based understanding of the interactions between soil type, climate, biodiversity and management that drive N turnover and storage in grasslands.

We quantified SON and SOC stocks as well as δ15N isotopic signatures for 25 grassland plots in each of the three exploratories, covering a wide range of LUI. Currently, the results for the Schwäbische Alb exploratory are available. These data clearly show the importance to distinguish for the individual effects of LUI components. For example, SOC and TN concentrations and stocks in the top 30 cm of soil tend to increase with LUI, but this increase is largely driven by the individual effect of the grazing component of LUI. The C:N ratio on the other hand was largely impacted by mowing and fertilization.

Our results indicate that grazing is the dominating management factor regulating SON and SOC stocks in calcareous grasslands of Southwest Germany, with grazing increasing SOC and SON stocks and associated soil functions. Further measurements and data evaluation will show whether this finding is of more universal importance for grasslands across Germany.

## Fate of cattle urine nitrogen on pasture and effect on N2O emissions

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### Abstract

Cattle excrete 75-95% of their nitrogen (N) intake. For dairy cows with a medium to high productivity, about 2/3 of excreted N is in the form of urine. During grazing, urine patches on pasture experience a large N input and thus form hotspots of potential nitrate leaching as well as emissions of ammonia and nitrous oxide (N2O). To investigate the fate of N in pasture urine patches and its effect on N use efficiency and N2O emissions, we performed a field experiment with controlled application of synthetic urine with typical patch sizes. Multiple urine applications were carried out between 2020 and 2023 on fenced-out areas of a pasture field in Switzerland. The different application times allowed to study the influence of varying environmental conditions, and in selected experiments the effect of patch characteristics was investigated (Barczyk et al., 2023). Repeated measurements after application included ammonium and nitrate concentration in the soil profile, exchange of N2O, and harvest N yield. In selected cases, $^{15}$N labelled urine was applied and allowed to determine urine N recovery in the soil and in harvests.

The observations indicated typical lifetimes of the applied urea (1-2 days) and its direct product ammonium (30-40 days) that was further converted to nitrate with a longer lifetime (2-5 months). The N2O emissions showed decay times similar to ammonium in the top soil, which suggests nitrification as the dominant source process. $^{15}$N recovery rates indicated a large loss of urine N probably trough nitrate leaching.

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## 1.8 Special session 7- Nitrogen Communication

### 1.8.1 Oral Presentations

## How much do consumers care about their nitrogen footprint?: A comparative study with other environmental labels

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### Abstract

This study aims to assess consumer preferences for a nitrogen footprint, a carbon footprint, and Forest Stewardship Council (FSC) certification, to highlight consumer awareness of the nitrogen footprint by comparing consumer preferences for the three environmental labels, and to explore the drivers of consumers' willingness-to-pay (WTP) to reduce the nitrogen footprint. Our society is suffering from nitrogen-related issues (Sobota et al., 2015). Consumer choice of nitrogen-less foods is an important for reducing nitrogen use (Oita et al., 2016). This study uses an online survey of Japanese consumers and choice experiments with milk. The main findings are as follows. Consumers are generally willing to pay extra to reduce the nitrogen footprint. The results indicate that Japanese consumers are willing to pay 4.47 JPY (95% confidential interval = [4.30, 4.63]) for an additional 1 g-N reduction in milk production, 46.4 JPY ([42.0, 50.8]) for an additional 1 kg-$CO_2$ reduction, and 56.0 JPY ([49.8, 62.1]) for FSC. These results suggest that Japanese consumers will pay for nitrogen reduction, and the amount of WTP for nitrogen reduction is almost equivalent to the WTP for $CO_2$ reduction in the choice experiment settings. Furthermore, several factors are identified that influence WTP for nitrogen reduction. For example, knowledge of the footprints and negative impacts of agriculture on the environment and an agricultural activities experience increase WTP for nitrogen reduction. Based on the results, consumers may be motivated to reduce the nitrogen footprint of their consumption, as well as carbon reduction and forest conservation, despite the low familiarity of nitrogen issues compared to other environmental issues.

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## Paving the path towards a better understanding of the nitrogen cycle in agricultural systems: a bibliometric analysis

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### Abstract

Understanding the dynamics of the nitrogen (N) cycle in agricultural systems is crucial for sustainable food production and environmental management. The complexity of the N cycle spans across different topics, posing challenges not only in tracking its environmental dynamics but also across its representation in scientific literature. We aim to examine the existing literature to better highlight research trends, hot topics, and influential publications. To do so, we conducted a bibliometric study on 39,923 research studies from Web of Science for the period 1990-2024. The number of annual publications increased from 34 to 3745 between 1990 and 2023, showing a growth rate of 7.3 % $yr^{-1}$. We show that, globally, for each additional Tg N lost to the environment per the cropland N surplus, the average expected increase in total publications was 71. We identified contrasting relationships between the number of publications and the N surplus at the national scale, which are suggestive of the historical trajectories that different countries are following towards improving N management. As a conclusion, we summarized the N challenges in agricultural systems across different continents. This study can provide an important cornerstone to assess the effectiveness of efforts aimed at tackling N pollution within both research and policy arenas.

## Pursuing just and transformative adaptation to climate change through equal multi-stakeholder communication: A Case Study conducted by Kyoto Climate Change Adaptation Center

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### Abstract

Among the various adverse effects of climate change on agriculture, yield reduction directly relates to farmers' income. Therefore, it is one of the most urgent issues that require urgent action as climate change adaptation measures. The application of chemical fertilizers containing nitrogen to ensure stable yields is one option that can solve the problem in the short term. However, in the long run, there is an unavoidable trade-off between environmental pollution caused by nitrogen remaining in the soil without being absorbed by crops. To pursue the sustainable use of nitrogen in agricultural fields in a just manner that considers the actual conditions of the farmers, vigorous discussions among participants on an equal footing from different positions including farmers are one of the few effective ways (IPCC, 2022). Kyoto Climate Change Adaptation Center (KCCAC) conducted a year-long project to explore adaptation countermeasures through communication in the abovementioned manner among three different sectors; farmers, local government, and researchers. The method used was Future Design (Saijo, 2021), as introduced in the other report (Hayashi et al.). There, each vision created through their communication appropriately incorporated the circumstances of each position and ensured the well-being of the people.

The way of nitrogen use was also positioned in a balanced manner in the narrative. This report presents the details of the dialogue on the use of nitrogen in the actual discussions and thus serves one of the objectives of this session: to share experiences and ideas on N communications among the participants.

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## The nitrogen footprint of Denmark – Understanding the Danish consumption pattern and its effects on excess nitrogen into the environment

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### Abstract

Extensive literature on nitrogen footprint (N-footprint) models for the calculation of reactive nitrogen species (Nr) lost to the environment have increased in the past two decades. These N-footprint are based on the calculation methodologies from Leach and Galloway [1]. N-footprints are important evaluation tools to calculate current reactive nitrogen (Nr) losses to the environment stemming from multiple sectors and multiple entities. Denmark has long been an active proponent for sustainable development and nitrogen reduction policies [2].

The objective with this Danish N-footprint is to utilize the extensive data basses and create virtual nitrogen factors (VNF) that can be used to estimate the overall Nr lost to the environment on a per capita basis[3]. The N-footprint will calculate the Nr lost to the environment from four consumption sectors: (1) Food production and consumption, (2) Energy consumption, (3) Transportation and (4) Goods and services. This specific N-footprint tool is based on the individual's consumption pattern and is aimed at a more consumer-based analysis.

The Danish N-footprint will allow comparison to be drawn from other nations who have already calculated their footprints. The importance of country N-footprints is in its ability to use VNF for food or commodities imported from other nations. This allows for accounting of imported as well as exported goods but is based on the premises that each country calculates their own VNF. The Danish N-footprint is a critical tool for the Danish consumer to evaluate the sectors that contribute the most to Nr lost to the environment and the identification of possible reduction solutions.

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## Planetary and regional 'nitrogen boundaries' - effective for communicating nitrogen issues?

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### Abstract

The 'planetary boundary' concept has effectively highlighted the extensive environmental degradation caused by human activities. Human interference with the nitrogen cycle has been identified as one of the nine Earth System boundaries already exceeded. Despite its quick adoption in both the science and the policy arenas, operationalizing a 'planetary nitrogen boundary' is not straightforward and presents numerous challenges. Unlike climate change, nitrogen-related environmental problems predominantly manifest at regional scales, necessitating regionalized approaches for defining safe nitrogen levels. To address the need for information on the regional distribution of safe levels of excess nitrogen and exceedance of these levels, we developed an approach that derives safe levels of N losses to the environment while accounting for regional variation in the configuration of agro-ecosystems as well as the sensitivity of the receiving environmental compartments to excess nitrogen (Schulte-Uebbing et al., 2022). However, several environmental impacts of nitrogen, such as air pollution, are not yet considered in this framework. Rockström et al. (2023) recently proposed 'just' boundaries alongside 'safe' boundaries across different domains of the Earth System, aiming to minimize significant harm to humans from Earth system change. The 'just' nitrogen boundary was conceptualized as a threshold where humans do not experience harm from nitrogen-related water pollution, but did not yet account for the minimum required available nitrogen to ensure sufficient food production.

In this presentation, we critically review recent publications that operationalize 'safe' and 'just' nitrogen boundaries, evaluating their benefits and limitations. We identify areas of success and areas requiring further refinement to enhance the utility of nitrogen boundaries in effectively communicating nitrogen issues.

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## 1.9 Special session 8 – Nitrogen in Organic Farming

### 1.9.1 Oral presentations

## Contribution of livestock to organic agriculture: modelling nitrogen flows at the national scale

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### Abstract

The European Green Deal aims to expand the area of organic agriculture (OA) to 25% of agricultural land by 2030, compared to 9.9% at present. Recent studies that proposed scenarios for expanding OA have shown that nitrogen would be a major limiting factor (Barbieri et al., 2021), as the only source of nitrogen available to OA is biological nitrogen fixation by legume crops. In all scenarios, the number of livestock decrease compared to the present number, but livestock are necessary due to their dual function as a source of animal protein for food security and as a vector of circularity of nitrogen flows to cropland (Billen et al., 2021). There is an interest in quantifying the current state of nitrogen flows in OA at the national scale and highlighting the contribution of livestock to them to understand OA's capacity to develop within biophysical constraints.

We calibrated the ALPHA model (Chatzimpiros and Harchaoui, 2023) to simulate nitrogen flow and cycling in the national organic agri-food system of France, which has the largest area of OA in Europe.

The main inputs of nitrogen to OA in France were biological nitrogen fixation (51%), followed by atmospheric deposition (27%), conventional manure (11%) and organic feed imported from abroad (11%). Approximately 35% of the manure used to fertilise organic cropland came from conventional agriculture. Imported feed was used mainly to meet the nutritional requirements of monogastric animals (37% of total feed nitrogen) and, to a lesser extent, ruminants (6%). This study quantified the degree to which OA depends on external nitrogen inputs, which may limit its development.

### References

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Chatzimpiros, P., Harchaoui, S., 2023. Sevenfold variation in global feeding capacity depends on diets, land use and nitrogen management. NatureFood 4, 372-383. https://doi.org/10.1038/s43016-023-00741-w

## Clover grass for biogas enables farm gate nitrogen balance in organic farming

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### Abstract

Organic plant production relies predominantly on manure from organic and conventional livestock systems as source of reactive nitrogen. This dependency restricts the potential growth of the organically cultivated area where livestock density is low. Alternatively, utilizing clover grass fields offers a major source of reactive nitrogen. Yet, clover grass fields are predominantly embedded in farming systems with ruminant livestock, which limits their implementation in areas with low livestock density.

Using clover grass for biogas as nitrogen source for organic plant production represents an opportunity in Denmark where biogas plants are widespread, valorizing biomass while providing reactive nitrogen for organic plant production. Organically grown, un-fertilized clover grass is a sustainable energy crop since it lowers dependency on fossil hydrocarbons, and unlike energy crops, organic clover grass contributes little to global warming forcing due to absence of fertilizer nitrogen related greenhouse gas emissions (Parajuli et al., 2017).

In this work, we present an organic crop rotation relying exclusively on clover grass cultivated for biogas as nitrogen source. Twenty percent of the crop rotation is clover grass, which is returned to the farm via a biogas plant. Analysis of the farm gate nutrient balance reveals average nitrogen supply 65 kg $ha^{-1}$. Clover grass and legume crops take up 30% of the crop rotation. Therefore, the average nitrogen supply on fertilized fields in an organic crop rotation with clover grass is 115 kg $ha^{-1}$, which allows near to optimal nitrogen supply of organically grown crops in Denmark (Lauersen, 2022; Olsen & Mejnertsen, 2010).

### References

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## Higher than expected: Nitrogen use efficiencies over 35 years of organic and conventional cropping

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### Abstract

Here we present N budgets based on field data records from the longest lasting organic-conventional system comparison worldwide. In the DOK - bio-Dynamic, bio-Organic, Konventionell - field experiment, organic and conventional mixed cropping systems have been compared since 1978 at two fertilization levels, with level 2 being typical for the respective system and level 1 half of it. Controls are a conventional treatment receiving solely mineral fertilizers and an unfertilized treatment. Symbiotic $N_2$ fixation was quantified based on $^{15}N$ studies and legume N yield data. Topsoil (0-0.2 m) N stock changes were derived from the time course of soil N concentrations. Soil surface and soil system N budgets were computed from 1985 until 2019. With 75 to 122 kg N $ha^{-1}$ $year^{-1}$, symbiotic fixation was the main N input for most treatments and hardly differed between fertilization levels. Soil surface budgets resulted in balances ranging from negative values of -31 kg N $ha^{-1}$ $yr^{-1}$ to surpluses of +46 kg N $ha^{-1}$ $yr^{-1}$. Nitrogen use efficiencies (NUE in %; N output / N inputs x 100) of treatments with negative balances resulted in values >100%, while treatments with positive balances had NUEs of 85% to 99%. Thus, fertilizer NUE suggested equally high NUE for mineral fertilizer N and some manure treatments (around 90% at level 2). Topsoil N stock changes ranged from -26 to +9 kg N $ha^{-1}$ $yr^{-1}$. Negative balances indicated soil N mining, while positive balances pointed to a risk of N losses and/or to N accumulation in soil.

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# Recycling and sources of nitrogen to double the organic farmland of Denmark – a knowledge synthesis

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## Abstract

A recent knowledge synthesis (Eriksen et al., 2023) investigated if it will be possible to achieve sufficient nitrogen to double the organic area of Denmark from the current 300.000 ha, which is equivalent to 12% of the Danish farmland. Diverse sources based on improved recycling on-farm, between farms, and from nature, cities and industry to farms were included in the analysis. The sources were currently allowed to use according to the Danish regulation of organic farming, some with limitations. The analysis was performed under the assumption of no changes of the organic animal production from the current relatively high level, and the increase to 600.000 ha of organic farmland was assumed to take place in the area of organic plant food production. No currently unknown technological improvements were included. The main sources were found to be: increased recycling by improved management methods on-farm, production of green manures and plant-based fertilizers from legumes and catch crops, improved distribution of conventional and organic animal manures between farms, return of biogas residues, and recycling of nature, urban and industry waste resources to fields. Several barriers were identified, which could be aimed to resolve. Overall, the analysis showed that there is sufficient nitrogen sources available to double the organic farmland of Denmark.

## Reference

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## Efficacy of plant biostimulants under optimal and suboptimal N applications on organic potato

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### Abstract

Plant biostimulants (PBs) in the EU are categorized as fertilizing products that stimulate plant nutrition by improving nutrient availability and Nutrient Use Efficiency (NUE). A recent meta-analysis reported that PBs can increase various crop yields by an average of 17.9% under field conditions (Li et al., 2022). However, their efficacy varies depending on climate, soil type, and application method. Research on the effects of PBs on macro-and micronutrient availability and NUE is limited.

Field experiments were conducted at two locations with different soil textures: sandy loam in 2021 and sandy soil in 2022 at Aarhus University in Denmark. We evaluated the efficacy of six commercially available biostimulants of various origins (microorganisms, humic substances, plant, and seaweed extracts) on organic potato yield and NUE at two nitrogen fertilization levels (100% and 50% of recommended nitrogen).

There were no interaction effects between PBs and nitrogen levels on potato yield and NUE at both locations, indicating that the effects of PBs do not depend on the N level under the current experimental conditions. Nitrogen showed an effect on total tuber yield only in sandy loam soil ($p<0.01$). Some of the PBs increased yield ($p=0.03$) and slightly improved the uptake of all macro and micronutrients except Fe in sandy soil, but only P and Mg uptake in sandy loam. The results indicate that the efficacy of PBs application on yield and nutrient uptake in organic potato production varies depending on the type of PBs and location, but not on the nitrogen application levels.

### References

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## Can mulch and cover crops provide better nutrient status in vegetables?

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### Abstract

The bottlenecks for increasing the production of organic rowcrops are primarily, nutrient supply on farms with no livestock, a high weed pressure and the need for crop rotation to reduce disease pressure. To increase yield, it is thus important to increase the nitrogen availability as well as to reduce the loss of nutrients.

Using chopped gras as mulch is a mean for applying nitrogen as well as controlling weeds. In a study from Norway the recovery rate of mulch derived nitrogen was found to be between 13 – 20% (Riley et al. 2003). From a recent study we found that 2 -3 applications of chopped gras mulch in leek gave a significantly higher yield than the control using recommended dose of nitrogen fertilizer. In onion the mulch applications gave the same yield as the control treatment.

In vegetable production large amounts of plant biomass may be left on the soil following harvest and represent a risk of nutrient leaching. Plant uptake of nitrogen during the winter drainage period can reduce the risk of leaching loss, thus cover crops is a mean to achieve this. A limiting factor in Norway is short growing time following harvesting of vegetables. However, cover crops seems in our studies to increase the retention of nitrogen in the upper soil layer and thus increase the availability for the following crop.

In this presentation data from more studies into use of mulch as a nutrient source and cover crops for retention of nitrogen in Norway will be presented.

### References

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# 2 Part 2 – Poster presentations

## 2.1 Session 1: How to increase nitrogen use efficiency

Improving Nitrogen Use Efficiency (NUE) Through Nanoscale Non-Covalent Urea Derivatives

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## Abstract

Increasing nitrogen use efficiency (NUE) of granular urea fertiliser is key in the maintenance of soil and plant health while also meeting global food demands[1]. A common management technique to improve NUE is through the use of enhanced efficiency fertilisers (EEFs); however, these techniques have drawbacks including the presence of toxic or non-biodegradable components, costly development and manufacturing procedures, often showing irregular nutrient release and ineffective slow delivery of nutrient[1].

In recent years an alternate method to preparing EEFs based on crystal engineering has been proposed[2]. Cocrystals, classed as a non-covalent derivative (NCD), are formed when two or more ionic or neutral molecules are arranged in a structurally defined crystal held together by non- covalent bonds[3]. These can be formed as coatings on urea granules with urea itself being part of the cocrystal. Such uniquely ordered nanoscale mixtures exhibit markedly different physical properties when compared with their component molecules. Thus, these unique properties makes NDC a possible economic and environmentally friendly alternative to current EEFs for control of urea release.

This research outlines our development and characterization of a set of novel urea-dicarboxylic acid cocrystals. Full chemical characterization of the cocrystal/s have been undertaken and release of urea from these cocrystals in water and soil have shown promising results. Findings from this research explore the possibility of developing novel and environmentally benign EEF products whilst minimizing production costs and optimizing NUE.

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# Is the use of nitrogen transformation inhibitors a feasible and safe measure to achieve climate and environmental goals in agriculture?

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## Abstract

The usage of urease and nitrification inhibitors for nitrogen transformation manipulation are increasingly propagated to reduce ammonia and nitrous oxide emissions from the application of nitrogen fertilizers. Their use may become even more important after the year 2030 when the agricultural sector will be obliged to make more significant contributions to the ambitious European climate targets. But potential risks of large-scale application of these inhibitors for human health and ecosystems have not yet been sufficiently investigated. In addition, the data on the fate of the substances in the environment is patchy and the specific effectiveness of various active ingredients has not yet been sufficiently researched.

These uncertainties have so far only partially been considered in the legal regulations at EU and national level. This can be seen, for example, in the fact that substances such as Nitrapyrin, 1,2,4 Triazole or 2 NPT are authorized as inhibitors in the EU, but would with high probability not be approved under the EU-regulation for plant protection products. This is the case although the application to the open environment as well as the quantities applied are similar for inhibitors and plant protection products.

The paper will report estimated emission reduction potentials of inhibitors, highlight possible risks to the environment and health, discuss the scientific analysis of efficacy and critical review the authorization procedures. Finally, we make recommendations on how approval procedures can be improved and corresponding risks reduced.

## Gas Chromatography vs. Middle-Infrared Laser Absorption Spectroscopy – A comparison of methods for measuring greenhouse gas emissions

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### Abstract

Closed chamber measurements using the non-steady-state technique are a widely used approach for measuring greenhouse gas (GHG) fluxes in agricultural ecosystems (Klein et al. 2020). To calculate GHG fluxes, gas samples must be taken from the chamber by either a mobile gas analyzer which allows continuous monitoring of the concentrations in real time or with syringes and subsequent analysis by a gas chromatograph. In our study, we compared both methods by carrying out simultaneous measurements with a closed chamber in different treatments of a long-term field experiment and i.) analyzed the gases in real time on the field with a MIRA Ultra $N_2O/CO_2$ and a MIRA Ultra Mobile LDS: $CH_4/C_2H_6$ analyzer using Middle- Infrared Laser Absorption Spectroscopy (Direct Absorption) by AERIS Technologies, Inc. or ii.) samples were taken with syringes at six points in time and subsequently analyzed by gas chromatography. The preliminary results, calculated with robust linear regression, show a high level of agreement particularly for the fluxes of $CO_2$ ($R^2$=0.9796) and $N_2O$ ($R^2$=0.956). Fluxes of $CH_4$ deviated stronger from each other ($R^2$=0.3164), which may be an indication of a deficiency in the analytical technique of either method but may also be due to the much higher sensitivity of the MIRA analyzers ($N_2O$: < 200ppt/s, $CO_2$: <200ppb/s, $CH_4$: <1ppb/s) and the higher minimum detectable flux of the GC. Further investigations are planned to verify the results. The presented results will support an informed selection of a suitable method with its advantages and disadvantages for measuring GHG fluxes in the field.

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## Accurate assessment of grass nitrogen status from sensors and the critical nitrogen dilution curve

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### Abstract

The critical nitrogen dilution curve (CNDC) is efficient for diagnosing crop nitrogen (N) deficiency. Optical sensors deployed on at field- or airborne scale can partly answer the question of how much and when to fertilize. Crop biomass estimated from remote sensing data linked with crop N status by parametric regression involving models of linear or nonlinear nature has been shown to allow assessing plant N requirement and real-time variable-rate spread of fertilizer N (Peng et al., 2021). For perennial crops, including grasses (family Poaceae), deriving CNDC is not straightforward due to in-season modulations by cuts and fertilization. The objective of this study is to estimate precisely the amount of N fertilizer needed for optimal grass growth between two consecutive cuts according to its N requirement and the CNDC. Comparative approach studies the potential of data from two multispectral sensors (Yara N and UAV-mounted) and machine learning regressions (random forest and alike). Field experiment was initiated in September 2021 with ryegrass (Lolium perenne) on a sandy loam soil in Denmark, with five nitrogen rates. We present results of the first production years 2022-2023 of canopy multispectral reflectance and CNDC developed for the grass and provide novel insight for improving grass N diagnosis and their management in Denmark. Grasses can be grown across nearly all Europe and with proper N management have the potential to also offset reactive N flows, including leaching to ground- and coastal waters, while increasing soil carbon sequestration (Manevski et al., 2018; Chen et al., 2022).

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## Nitrogen mineralisation from soils: Insights from a distributed microlysimeter experiment

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### Abstract

Nitrogen (N) is the most important nutrient to agricultural crops that is supplied through the soil. At the global scale, a large share of cropping systems rely on the natural N supply from decomposing soil organic matter, as the farmer's access to mineral fertiliser or additional organic matter inputs is limited. Simulation models are commonly used to investigate the behaviour of cropping systems for evaluating management options and productivity performance, also under limited N. However, experimental data on N mineralisation under field conditions to inform these models, is rare, especially from tropical and subtropical environments. Beyond current knowledge implemented in such models, laboratory incubation studies suggest that the soil itself takes a major role in the organic matter turn-over, adding to the already considered moisture and temperature controls (Nendel et al. 2019). With the objective to further improve process-based simulation models for agroecosystems, we have run a multi-year microlysimeter experiment across different climate zones, supplying time series data of N leaching from shallow soil cores under field conditions. A first assessment of the data, reveals that (i) there was a significant correlation between mineralogical soil properties with soil organic matter, but not with mineralised N in the microlysimeters and (ii) that the current methodological approach is problematic when being applied in the tropics, due to a strong release of N, which is contradicting the laboratory results. Assuming a role of N being trapped in soil aggregates, an improvement of the method is suggested for a second generation of this experiment.

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## Maize inoculation with microbial consortia: contrasting effects on rhizosphere activities, N acquisition, and plant growth under different N supply

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### Abstract

The benefit of plant growth-promoting microorganisms (PGPMs) as plant inoculants and its interaction with different N supply is influenced by a range of environmental factors.

Therefore, microbial consortia products (MCPs) based on multiple PGPM strains have been proposed as superior for improved plant growth and nutrient use efficiency in disturbed soil environments. The performance of a MCP was investigated in greenhouse maize experiments with maize with different N supply (nitrate and ammonium), contrasting pH, organic matter content and microbial activity. Interestingly, the MCP inoculant stimulated plant growth and improved acquisition of macronutrients only on a freshly collected field soil with high organic matter content and high background microbial activity, exclusively in combination with stabilized ammonium fertilization. This was associated with transiently increased expression of AuxIAA5 in the root tissue, a gene responsive to exogenous auxin supply, suggesting root growth promotion by microbial auxin production as a major mode of action of the MCP inoculant. High microbial activity was indicated by intense expression of soil enzyme activities involved in C, N and P cycling in the rhizosphere (cellulase, leucine peptidase, alkaline and acid phosphatases) without detectable effects induced by MCP inoculation. The results demonstrate that the MCP strategy, combining large numbers of PGPM strains with complementary properties, not necessarily translates into plant benefits under challenging environmental conditions. Soil properties, such as organic matter content, pH buffering and the form of N may crucially influence the plant-microbial interactions, plant-protection metabolism and thus contribute to an improved nitrogen use efficiency accordingly [3].

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## EXPECTED RESPONSE IN A QPM AFTER THREE CYCLES OF SELECTION FOR TOLERANCE TO LOW SOIL NITROGEN

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### Abstract

Maize is the most important cereal crop worldwide base on its production of 1.2 million metric tons in 2023/24 (Shahbandeh, 2024). Low and declining soil nitrogen (N) is a major abiotic stress limiting maize yield in sub-Saharan Africa. To solve the problem of food and nutrition insecurity in the region, there is need to develop quality protein maize (QPM) with tolerance to low soil nitrogen. A QPM, ART/98/ILE 1-OB, was made to undergo three cycles of S1 recurrent selection for improvement for tolerance to low N. About 150 S1 individuals were generated for evaluation in each cycle. Evaluation was done on low N site at Ilora and Ile-Ife out-stations of the Institute of Agricultural Research and Training, Nigeria, under low and high N conditions. Low and high N blocks received 30 kgN/ha and 90 kgN/ha, respectively, in form of urea. In each cycle, the top 15% S1 individuals were selected to move to the next cycle. Data were collected on agronomic, yield and low N traits. Means of traits were not significantly different under low and high N conditions. Expected response from selection revealed that plant height and plant- ear height ratio will increase slightly by 9%. Grain yield is expected to increase by 40% at cycle 3 indicating yield increase of about 0.7 tons/ha. The high heritability of grain yield (37.4%) under low N also corroborates the high response. The results indicated that S1 recurrent selection has been effective in improving the maize population for tolerance to low soil nitrogen.

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# Enhancing the fertiliser value of digestates from biogas plants through biomass pre-treatment and optimisation of operation parameters

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## Abstract

The increasing shift towards using high dry matter recalcitrant biomasses coupled with sub-optimal operation conditions in biogas plants results in digestates characterised by high dry matter content and partially decomposed organic matter. This negatively affects the nitrogen fertiliser value of the digestates and potentially causes higher ammonia losses. Current anaerobic digestion (AD) processes primarily focus on optimising biogas yield while overlooking the quality of the digestate. To address this, a paradigm shift is needed where biogas and digestate quality optimisation is prioritised, potentially resulting in a digestate with a higher fertiliser value to substitute more mineral fertilisers and reduce losses. This experimental study explored how biomass pre-treatment techniques (ultrasonication, electrokinetic, ensiling and thermal pre-treatment) and biogas operation parameters (temperature and hydraulic retention time) influence digestate nutrient availability and fertilising properties of the digestates.

The effects of biomass pre-treatment on nutrient availability varied. For instance, electrokinetic treatment significantly increased available N in the digestates, but the effect levelled off after a secondary AD step. Ensiling of straw prior to AD increased inorganic N and S release in soil compared to non-ensiled straw, while high-temperature thermal treatment reduced the digestate fertiliser value. The choice of the optimal biogas operation parameters (i.e. digestion temperature and HRT) was greatly influenced by feedstock type. A second digestion step enhanced digestate fertiliser value without negatively affecting carbon retention in the soil. Understanding these variables is essential for designing an integrated biogas-digestate optimisation approach for enhanced biogas production and nutrient availability in digestates for higher crop nutrient utilisation.

## Measurements of gaseous losses from organic residues as fertilizers

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### Abstract

When organic residues are used as fertilizers, nitrogen losses can be as high or higher than when mineral fertilizers are used, including gaseous losses to the air (Charles et al. 2017; Wester-Larsen et al. 2022). To reduce losses, accurate assessment of losses with different managements and mitigation options are required, but measurements of losses to air are often expensive and labor intensive. Ammonia is the most important loss, whilst nitrous oxide is important because it is a greenhouse gas (GHG). Usually, GHG's and ammonia are measured separately with different methods, but when organic or ammonia-based fertilizers are used, both can occur simultaneously. We have developed an open dynamic chamber system based on Pape et al. (2009) that can sample both, and have it analyzed automatically. Different flow rates can be used so that both low and high concentrations can be measured. The system was developed with low cost and versatility in mind. It has been tested with digestate in soil.

Results from this test will be presented and discussed.

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## Fertilising the system, not just the crop: New strategies in Australian dryland cropping systems

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### Abstract

In contrast to the overuse of nitrogen (N) fertiliser in subsidized, high-yielding grain production systems (Europe, USA, China), inadequate N supply threatens the productivity and sustainability of Australian (and other) dryland cropping systems. Inadequate N supply is the major cause of the 20-40% attainable "yield gap" and causes N "mining" from existing soil organic matter (SOM) which if accounted, increases the GHG footprint of the farming system. Farmers are mostly driven by the risk of dry conditions limiting return on N investment and increasing concerns about GHG emissions from more N fertiliser. We explored two novel N supply strategies using a system, rather than an individual crop approach to N supply. The first involved supplying supplementary nutrients (NPS) to crop residues at rates that mimic the nutrient stoichiometry of the soil microbes to improve the conversion of crop residues to stable SOM (Kirkby et al., 2016).The strategy reversed SOM decline and increased stable soil carbon cost-effectively by 9.9 t/ha over 8 years which more than offset GHG emissions (Kirkegaard et al., 2022).The second "N-bank strategy" replaced the current tactical, seasonally adjusted N top-dressing, with a fixed annual N target linked to long-term yield potential (Pandey et al., 2024). The strategy aims to avoid the costly risk of inadequate N in good seasons and assumes most unused N in semi-arid systems is not lost but persists to support subsequent crops. The effectiveness of the strategy in systems experiments over 6 years in southeastern Australia will be discussed.

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# From terrestrial to aquatic ecosystems: cross-scale sensing for assessing agroecosystem nitrogen use efficiency and water quality in the US Midwest

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## Abstract

Nitrogen (N) is the most demanding nutrient for crop growth, but excessive fertilization leads to environmental degradation. The US Midwest contributes to one-third of global maize production and also leads to severe downstream eutrophication to the Gulf of Mexico. High spatial and temporal resolved information of ecosystem N dynamics is urgently needed to support efficient N management for achieving high crop yield and minimizing environmental risks (Wang et al., 2021). Satellite remote sensing can cost-effectively monitor terrestrial and aquatic ecosystems to track N flows. However, the accuracy is often compromised due to insufficient ground truth data. This study proposes to develop a cross-scale sensing framework (Wang et al., 2023a) to integrate satellite, airborne, and ground measurements to provide a scalable solution to quantify high-resolution regional N dynamics from terrestrial to aquatic ecosystems in the US Midwest. In this framework, we developed radiative transfer process-guided machine learning algorithms (Wang et al., 2023b) to improve predictive performance and reduce the need for ground truth data. Results show that this cross-scaling sensing framework shows high accuracy in detecting regional scale crop N ($R^2$=0.76 relative RMSE = 14.95%) and inland water body chlorophyll concentrations ($R^2$=0.62 relative RMSE = 23.52%) in the US Midwest. We found that rivers and lakes in watersheds with low crop N use efficiencies have high chlorophyll concentrations. We highlight that cross-scale sensing with process-guided machine learning has high capability to scalably and timely monitor regional ecosystem N dynamics to support sustainable nutrient management.

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## Machine learning and Remote sensing experiments to determine biomass and nitrogen in winter wheat – implementation and challenges.

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### Abstract

Appropriate nitrogen (N) fertilization is used to improve farm profits, meet product quality objectives, and reduce environmental impacts such as N2O emissions and N leaching from agricultural soils. Soil health, in particular total soil N, is an important factor controlling crop biomass productivity and hence food security. Remote sensing imagery has the potential to provide information on soil N and crop aboveground biomass over large areas. This study aimed to investigate the correlation between estimated biomass and total soil N in winter wheat and to model biomass based on remote sensing. We used machine learning approaches such as Random Forest (RF) to map winter wheat biomass in Denmark using Landsat satellite vegetation indices (VI), a digital elevation model (DEM), and general soil and climatic parameters. Our results show that winter wheat biomass in Denmark shows significant spatial and interannual variability from 2013 to 2023, and that Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index2 (EVI2) were highly correlated with biomass. This research provides effective indicators for accurate biomass modelling based on satellite imagery at national scales. We conclude that different environmental factors and remote sensing data are a valuable combination of information sources for decision making.

**Keywords:** Soil nitrogen, biomass, remote sensing, machine learning and food security.

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## Improving nitrogen use efficiency in crop production systems: is there enough nitrogen in the soils?

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### Abstract

Improving nitrogen (N) use efficiency in crop production systems is urgently needed to reduce N losses to the environment and protect water quality in waterways. Nutrient recommendations for various crops in developed countries are tailored to maximize crop yields. For Maize, N recommendations are based on 1970s research on crop N needs that did not account for N supplied by soils. Hence, most research has ignored a potential way to develop N recommendations: understanding the soils' capacity to supply N over a growing season. We are conducting research in the State of Maryland (most downstream state in the Chesapeake Bay Watershed) to improve N use efficiency in cropping systems (Maize–Soybean). Our current N recommendations for Maize are based on yield goals, where farmers are allowed to apply 1 pound of N for each bushel yield of Maize. Various states in the United States follow a similar N recommendations philosophy, which is that they apply 1 to 1.5 pounds of N per bushel. These recommendations do not take into consideration the ability of soils to provide N, and thus, more N that crop needs is typically applied with fertilizers. This has a deleterious effect on water quality impairment with excess N. We need new approaches to address and improve the N use efficiency. This presentation will discuss our current research on investigating the temporal N pools in farmer's fields planted with Maize, lessons learned, and a path forward to address the N dilemma in agricultural watersheds.

## The Impact of Mn and S Soil Application on N Cycling and NUE in a Winter Wheat Lysimeter Experiment

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### Abstract

Global wheat yields depend on the use of N fertiliser. The prolific use of N fertiliser significantly impacts water quality and greenhouse gas emissions. If we want to operate within the current food system and the planetary limits of N pollution, N use efficiency (NUE) would need to be dramatically increased.

A two-year outdoor lysimeter experiment was conducted to test whether Mn and S application would influence winter wheat (Triticum aestivum; Graham variety) NUE, N pollution and crop yield. Leptosol soil collected from the topsoil horizon in a long-term conventional tillage farm in southeast England was used. The researcher measured soil pH, organic matter, plant available nutrients, texture and cation exchange capacity. Treatments of control, S (25 kg $ha^{-1}$) and Mn (20 kg $ha^{-1}$) were applied in solution to the soil at growth stage (GS) 12 in an incomplete factorial design with five replicates per treatment. The researcher applied N in solution at 0 and 300 kg/ha. Each N treatment was applied over GS30, GS31 and GS37, with half the total N applied at GS31. Each lysimeter contained three plants.

Leachate was collected weekly. Monthly composite samples were measured for $NH4^{+}$ and Total oxidised N. Following the first growing season, N2O and CO2 fluxes were measured using a Photoacoustic Field Gas Monitor. Gas measurements were taken at critical management interventions (ploughing, reseeding, fertilising) and after rainfall.

This presentation will discuss the experimental set-up, yield, protein yield, gas fluxes, and N leachate results.

# Optimized Experimental Designs for EONR Estimation: A Model Averaging Approach

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## Abstract

The global challenge of optimizing nitrogen use in agriculture requires innovative approaches to maximize crop productivity while minimizing environmental impacts. In this study, we adopt a model averaging framework, addressing model selection uncertainties and ensuring accurate Economically Optimum Nitrogen Rates (EONR) estimation to find an optimal experimental design. This is achieved through a strategic focus on the design phase, where we meticulously develop experimental designs tailored to maximize efficiency in model parameter estimation. Optimal experimental design principles guide the efficient estimation of model parameters, emphasizing the design of inputs (nitrogen rates) to minimize the variance of parameter estimates while reducing the number of costly experiments. By methodologically reparameterizing key nitrogen response models—quadratic, quadratic plateau, Mitscherlich, and linear plateau—this study integrates EONR as a unified parameter, enhancing model reliability and experimental outcome precision. Our approach uses Akaike's Information Criterion (AIC) for model weighting, proposing a robust experimental design that adapts to model variability, thereby ensuring more accurate optimization. Findings underscore the importance of strategic experimental setup in nitrogen studies, suggesting that precision in EONR estimation can lead to tailored nitrogen applications, reducing excess use and environmental leaching. This study contributes to the broader discourse on sustainable agriculture by offering a pathway to fine-tune nitrogen inputs, aligning with global efforts to resolve the nitrogen dilemma.

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## Coupling cropping system and bioeconomic optimization models to assess nitrogen circularity in European Diary Production Systems

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### Abstract

European farms face criticism due to adverse production effects, e.g., the loss of nitrogen (N). The concept of circularity has recently been discussed to alleviate such environmental pressure (De Boer et al., 2018). Still, the efficiency of circularity in increasing sustainability on farms remains under-researched. To assess this, we propose a holistic approach based on coupling the cropping system model ARMOSA (Perego et al., 2013) with the bioeconomic optimization model FarmDyn (Britz et al., 2019). ARMOSA simulates crop growth, water, and N dynamics under different pedoclimatic conditions. FarmDyn provides an integrated framework to optimize farm management, including cropping, herd management, and investment decisions that a farmer would face. Here, ARMOSA outputs are used to estimate statistical meta-models using different fertilization levels (mineral and manure) for various crop rotations under site-specific conditions. The meta-models are implemented in FarmDyn as N response curves at crop and crop-rotation levels to reflect N dynamics at different fertilization rates in the models' cropping decisions. This includes information on N losses (gaseous, leaching, runoff) and changes in soil organic carbon.

N emissions and imported N in farm inputs calculated in FarmDyn are used as proxies for circularity, and N use efficiency. The framework is applied in scenarios of stepwise reduction of the proxy to enforce circularity. The results can be interpreted as marginal abatement cost curves, hinting at the potential costs of circularity and promising levers to increase farm sustainability. For the final contribution, we plan to test the framework on selected European dairy farms.

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## Optimizing circular nutrient re-use for bio-based fertilizers: evaluating effectiveness of new bio-fertilisers in different crops.

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### Abstract

Overuse of nitrogen fertilisers is a cause of concern due to the impact on ecosystems and associated repercussions, prompting the exploration of more environmentally friendly alternatives such as bio-fertilisers. This study is based on the agronomic evaluation of different vegetable crops after receiving soil amendments with new bio-fertilisers formulated using building blocks obtained from valorized vegetable wastes. The building blocks obtained were: compost, microbial biomass, insect frass, insect biomass and biochar. These bio-fertilizers were tested at three European countries (Belgium, France, and Spain) as part of the RUSTICA project, in leek, lettuce and tomato crops, respectively. Each region has designed different formulations of bio-fertilisers according to the nutritional requirements of each cropping and soil system. No mineral fertilisers were applied in Belgium and France, and a reduced strategy of mineral fertilisation was applied in Spain. In Belgium and France, the bio-fertiliser treatment was compared with conventional treatments using mineral fertilisers.

Analyses of crop nutrient uptake and yield production were conducted. Bio-fertilisers effect on soil properties, such as water retention and nutrient release, were also measured. Preliminary results indicated that, compared to mineral fertilisers, the bio-fertilisers reduced nitrogen leaching into the soil while providing crop nutrient needs. Additionally, they increased soil organic matter content and improved water retention, compared to conventional fertilizers. Notably, bio-fertilisers with higher biochar content demonstrated higher water retention in the soil. Commercial yield obtained were 35.4 kg/m$^2$, 7.7 kg/m$^2$ and 12.0 kg/m$^2$ for leek, lettuce and tomato crops, respectively, without significant differences observed among treatments.

**Keyword:** circular economy, bio-based fertilisers, biochar, waste valorization.

Timely petiole measurements using NIR to improve the nitrogen use efficiency in Australian cotton.

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## Abstract

Current protocol to monitor the in-crop nitrogen status of Australian cotton consists of collecting petioles at strategic growth stages (ie. early-mid squaring, first flower and boll set). The petioles are sent to laboratories for analysis and the results are returned within a two-week period. The nitrate-N results (ppm) are entered into crop models (consultants may use their own or freely available industry models) to determine the nitrogen status of the crop. If the crop is deficient, the crop models will recommend an applied rate (N kg/ha). However, test results can take considerable time to come back to assist N management, thus risking yield if the crop is deficient. It is no surprise that the industry uses the petiole tests as a health check rather than assisting in making pre-emptive nitrogen decisions and thus nitrogen is applied before results are returned. Over several years a model was built for NIR handheld technology (www.honeag.com) to analyse petioles for nitrate-N. During the 2022-23 cotton season at the Australian Cotton Research Institute the model was tested to manage nitrogen in cotton. It was shown that the in-situ measurement of petioles using NIR saved 70 kg N/ha to achieve the same yield when compared to an industry applied rate of 270 kg N/ha. Using NutriLOGIC (crop model) and NIR, 200 kg N/ha was recommended, achieving an above average yield of 15.6 bales/ha. The field experiment was designed to test the ability to respond to N in-season management and was shown to be successful, improving the nitrogen use efficiency.

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## Village Level Fertilizer Management for Increasing Nitrogen Use Efficiency, Rice Yield and Household Income

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### Abstract

It's a focus for researchers to find suitable options for increasing rice yield and nitrogen use efficiency (NUE) especially in the villages where nitrogen (N) loss is common due to improper practices. Hence, an experiment was conducted at the farmer's field to determine the effects of different N management practices on rice yield and NUE in two consecutive rice growing seasons of Boro (dry season rice with full irrigation) and Aman (wet season rice with supplemental irrigation). The research comprised of five treatments viz., control (zero N), farmer's practice (FP) where prilled urea was used at recommended doses of N-fertilizer (RDN), biochar (2 t $ha^{-1}$) with RDN (BRDN), and urea deep placement (UDP) as urea super granule. Rice grain yield increased by 19, 41 and 57% in the Boro season and 13, 24 and 23% in the Aman season in the RDN, BRDN and UDP treatments, respectively, compared to the FP. The highest agronomic (23 t $ha^{-1}$), physiological (40 t $ha^{-1}$) and recovery (58%) efficiencies of N were found in the UDP followed by BRDN treatment in Boro rice. Similar findings were obtained in case of Aman rice. Although the BRDN treatment displayed the 2$^{nd}$ highest gross return, it showed a lower net return and Benefit-Cost ratio (BCR), primarily due to the added expense of purchasing biochar. Therefore, the UDP treatment appeared to be financially most rewarding with the highest gross return, net return, and BCR which emphasized its effectiveness in improving N-use efficiency and increasing rice yields.

## Long-term Effects of Residue Management on Nitrogen Use Efficiency and Crop Yields

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### Abstract

High post-harvest residual mineral N after faba bean and winter oilseed rape, fall mineralization, precipitation, and low pre-winter N uptake by subsequent winter wheat, result in a high risk of N losses. Literature suggests that microbial immobilization is promoted by lower N input per organic C. Consequently, the notion of post-harvest application of high carbon amendments (HCAs) emerges as a promising strategy to improve the temporal synchronization of N supply and uptake.

In a nine-year field trial encompassing six complete rotations of the target crop sequences, we evaluated the impact on N dynamics and crop yields of four residue management options:

- incorporating preceding crop residues (common practice)
- removing residues
- substitution by the HCAs winter wheat straw and sawdust

Previous studies reported an extremely delayed re-mineralization of retained N due to the rapidly decreasing decomposition rates of HCAs. This poses the risk of N deficiency during critical developmental stages negatively affecting crop yields. Therefore, our study quantified the effects of HCA application on crop yields over three consecutive seasons, weighing short-term drawbacks against long-term benefits.

Overall, findings suggest negligible yield losses from alternative treatments. However, at crop sequence level, N use efficiency was significantly reduced solely after sawdust application. This indicates long-term N retention, with the bound N contributing to stable soil organic matter (SOM). Notably, this organic N reservoir is expected to be gradually mineralized in a sustainable higher immobilization-mineralization equilibrium. In essence, our results highlight the potential of strategic residue management, which aims at enriching SOM while maintaining productivity.

Can biostimulants increase N use efficiency in tomato? Preliminary results from the Safe-H2O-Farm project.

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## Abstract

Intensively managed crops throughout the Mediterranean basin are typically supplied with significant inputs of fertilizers with severe environmental issues such as nitrate leaching. In the last years, many efforts have been made to reduce the impact of N fertilization on groundwater (Farneselli et al., 2018). In this context, the Safe-H2O-Farm project (PRIMA 2022) aims to investigate farm-scale innovative N management strategies promising to prevent and reduce land and water pollution due to agri-food activities on tomato (Solanum Lycopersicon L.) and olive (Olea europaea L.). Within N fertilization strategies, the use of biostimulants is considered a promising strategy to reduce the amount of N fertilize, due to the improvement of N use efficiency and crop N uptake (Cozzolino et al., 2021). A field experiment was carried out in 2023 in Central Italy on processing tomato grown at three different crop N nutritional status (optimal, sub-optimal, deficient N status) in order to verify the feasibility of biostimulants (seaweed extracts, protein hydrolysates and N-fixing bacteria) for reducing N doses. The following traits have been investigated: a) plant developmental, physiological and morphological traits at different phenological phases; b) leaf chlorophyll and nitrogen contents; c) crop yield; d) plant-soil N dynamics. The application of biostimulants increased the crop growth and yield especially at lowest N availability while had a slight effect at sub-optimal N availability (+ 40% and +15% over the control, respectively); no differences were observed in the chlorophyll content. The greatest increase of crop growth was measured at the maxim leaf development stage for the protein hydrolysates products.

Funding: The project was funded by the PRIMA Section 2 -Thematic Area 1-Water management: Topic 2.1.1- 2022: (RIA*): "Innovative farm strategies that integrate sustainable N fertilization, water management and pest control to reduce water and soil pollution and salinization in the Mediterranean- Safe-H2O-Farm"

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Microalgal biostimulant to improve nitrogen uptake in lettuce (Lactuca sativa L.)

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## Abstract

The new challenge for agriculture is to ensure ever-higher crop yields by meeting the demands of the consumer who is increasingly looking for healthy and safe products coming from sustainable agriculture. Nitrogen-based fertilizers play a crucial role due to their effect on plant growth, however, un incorrect agronomic use could have various influences on ecosystems and human health. One possible strategy to improve nutrient uptake by plant might be by the use of biostimulant and among them, those obtained from microalgae. In this work, the foliar application of extract of Chlorella sorokiniana was assessed as biostimulant on lettuce seedlings in order to achieve better agronomic performance in terms of nitrogen use efficiency (NUE) and final yield. The experiment was carried out in a growth chamber, controlling the climatic parameters and five pots used as biological replicates. The biostimulant effects were assessed by an in vitro phytotoxicity test and then in vivo, monitoring the physiological and agronomic traits, from sowing to harvest. In total, three foliar spray applications were done. Results showed that the investigated biostimulant positively influenced the growth of lettuce seedlings by increasing fresh and dry weights, primary and secondary leaf metabolisms, and, in particular, NUE was positively affected by reporting higher values than the untreated plant.

## Perception, Practice, Policy and Research Interfaces among stakeholders on Nitrogen Use Efficiency in Nepalese Farming Systems

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### Abstract

Nepal is a small agrarian country with mostly rural settings, diverse climate and topography. Agriculture remains the main stay of economy where about 62% the population is engaged in farming and agriculture contributes about 21 percent of GDP. Despite its importance, agriculture with low productivity and production lags behind in feeding the people. One of the main reasons for low productivity is the poor nutrient management in farm land, mainly Nitrogen. Chemical fertilizers including nitrogenous in Nepal has a short history of about 70 years. However, these became very popular gradually, and at present farmers are of the strong conviction that "no crop without Nitrogen". Nepal does not produce nitrogenous fertilizer and farmers always have to cry for it in the main crop season. They are bound to use it only at the time of availability; mostly out of time and in inappropriate doses leading to low use efficiency and pollution especially in the areas of newly growing commercial agricultural pockets. There is fertilizer policy in the country but does not mention much about Nitrogen. Government through agricultural research sysyem has made recommendation of N for almost all the crops cultivated but farmers are not following it due to various reasons ultimately resulting in low NUE. This papers highlights the status of NUE in major food crops in Nepal and depicts the need for viable interlink among farmers, researchers and policymakers to chalk out the practical action plan for increased agricultural production with increased NUE and reduced loss of nitrogen.

Key words: Practice, Policy, Nitrogen, NUE, Farming

# Nitrogen fixation in organic soyabean plants from the stable isotope perspective

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## Abstract

Symbiotic $N_2$ fixing activity of legumes is important in organic farming, therefore the growing body of research on atmospheric nitrogen accumulation of pulses has increased interest in legume cultivation also in cool-climate countries like Lithuania. However, the cultivation of pulses has many threats due to their high sensitivity to ongoing climate change, as well as biotic and abiotic stresses, which are frequently related to lower-quality legume beans.

However, this process is still poorly understood, especially in particular microclimatic conditions, and can be affected by many factors. Therefore, there is a need for reliable methods for nitrogen sources determination.

In Lithuanian Research Centre for Agriculture and Forestry (LAMMC) in 2015 – 2023 field experiments with different microorganisms and biostimulants were investigated to increase nitrogen availability in legumes and enhance protein accumulation in their seeds. Using stable isotope ratio method, the origins and fates of organic and inorganic materials were analysed. Multiple factors that influence isotopic composition including input and export pathways, internal N cycling dynamics, and the microbial and plant populations mediating N transformations were studied using $^{15}N$ natural abundance.

Our results have shown, that the natural abundance stable isotope ratio method is useful to analyse N transfer pathways from soil and air and reflects the significant difference in soybean N production, soybean seed quality, and nitrogen sources exploitation. Two varieties of soybeans (Laulema and Merlin) were distinguished with significantly different N utilization patterns. Two strains of B. japonicum used in commercial biostimulants Bactolife and Rhizofix 10 distinguished with the highest N fixation efficiency. Also, isotopic measures revealed the negative effect of several commercial N-fixing endophytic bacteria on soybean production and N accumulation, when applied on their own or in combinations with B. japonicum.

## Effect of mineral fertilizers and digestates on crop yields and N emissions in arable farming systems

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### Abstract

We investigated in large-scale field trials if substitution of different levels of N mineral fertilizers with digestates works without compromising yields or increasing N emissions. Sites differed in soil texture and management history, i.e. a heavy clay that has been exclusively mineral fertilized for many years and a sandy soil being intensively long-term organically fertilized. Crop rotation was maize/ wheat/ barley on the clay and maize/ rye on the sandy soil, respectively. Fertilization design comprised of different levels of either solely digestate or equivalent N amounts of granular mineral N fertilizer solely. We found that solely fertilization with digestate reflected in low N use efficiencies since turnover of organic N was slow. Further, high ammonia emissions occurred after spring application of digestate with trailing hoses in winter crops. Generally, plant growth and N turnover were limited by dry periods in spring and early summer. Therefore, mineral fertilizer equivalents of digestates on slowly reacting clay remained on a low level (40 - 60%) while being significantly higher on the sand.

Further, crops suffering from extensive dry periods in spring, in most cases did not meet standard yield expectations. Under these conditions, a 20% reduction in N fertilization had no effect on yield quantity and quality. However, if N fertilizer is applied at early plant development stages, N efficiency significantly improves; hence, this strategy is widely adopted in practice. Yet high concentrations of nitrate in the upper soil resulted in extreme emissions of nitrous oxide when intensive precipitation events caused waterlogging and thus anaerobic conditions.

Preferred Theme: How to increase Nitrogen Use Efficiency

# Nitrogen Use Efficiency of Rice grown under Different Nitrogen-based Fertilizer Management Technologies

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## Abstract

Nitrogen use efficiency fertilizers in paddy cultivations is less than 30%. This study evaluates the effectiveness of different N-based fertilizers on increasing NUE increasing in a paddy farming in Sri Lanka. Eight treatments: no N control (0N), 75, 100 and 125% of recommended rates of N as urea (75U, 100U and 125U, respectively), 75% of N as urea intercalated biochar pellets alone (75BCU) or with a synthetic nitrification inhibitor (75BCU+NI), 75U with a synthetic nitrification inhibitor (75U+NI) or with a botanical nitrification inhibitor (75U+BNI), were applied to paddy in a field experiment under irrigated conditions. Yields were significantly higher in N added treatments (13-42%) and on the average 14% higher yield was observed in 125U treatment than that of 100U during the three seasons. However, the agronomic efficiency was not statistically significant among treatments, but the highest was observed in 75U when averaged across seasons (15 kg gain yield/kg of N). Application of urea significantly increased the ammonia volatilization (AV). The cumulative AV during the season among N applied treatments varied from 1.8 – 8.2 % of added N and the lowest and the highest was observed in 75U and 75BCU treatments, respectively. Application of synthetic nitrification inhibitors (DCD+NBPT) together with 75BCU can reduce AV loss by more than 50%. Leaching and denitrification losses of N were not significantly different among N added treatments. Therefore, application of urea to paddy fields can be reduced by 25%, either with or without any other technology, under the conditions tested in this study.

Nodulation tolerance to ammonium in the model plant Medicago truncatula with 2 Sinorhizobium strains

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## Abstract

Nodulation in legumes is supressed when sufficient mineral nitrogen is available but low concentrations of ammonium have been shown to stimulate root nodule formation in some species. This creates an opportunity to search for legume varieties displaying increased nitrogen use efficiency under combined N-sources: low ammonium and N2-fixation. In this study, we evaluated the nodulation tolerance to ammonium using Sinorhizobium meliloti RCR2011, which is partially effective for N2-fixation with the model legume Medicago truncatula A17, and using S. medicae WSM419, which is an effective strain. We verified that 0.2 mM of ammonium significantly enhanced nodulation with both strains. However, pink nodules, which are indicative of active N2-fixation, were almost absent in the S. meliloti RCR2011-symbiosis under 1 mM supply of ammonium whereas the number of pink nodules was only slightly reduced in S. medicae WSM419-symbiosis when compared to plants inoculated under N-free conditions. The results indicate that nodule performance is more tolerant to ammonium in symbiosis between partners that are better matched for N2-fixation.

## Urease and Nitrification Inhibitor technologies boosting Nitrogen Use Efficiency

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### Abstract

Modern agriculture is facing the dual challenge of responding to a raising demand for food and a reduction of arable land per capita, with farmers needing to cope with boosting yields whilst addressing climate and environmental challenges.

While Nitrogen (N) fertilisers play a pivotal role in increasing crop productivity, only about 50% of Nitrogen applied through fertiliser is absorbed by plants while the rest is released into the atmosphere, in deeper soil layer, the ground water and/or fixed at soil particles. These losses pose a challenge for human health, climate and biodiversity.

This presentation explores the potential of Nitrification and Urease Inhibitors (NI and UI), efficiency enhancers technologies that can improve Nutrient Use Efficiency and climate change mitigation by minimizing nitrogen losses.

NIs and UIs benefit both the environment and farmers by being part of the solution for a sustainable and effective nutrient management and by significantly reducing GHG, ammonia emissions and nitrate leaching from nitrogen fertilisation.

By integrating inhibitors into fertiliser management practices, farmers can optimize nitrogen use efficiency while minimizing the environmental impact of fertilizer use.

The presentation will also illustrate the role of Fertilisers Efficiency Enhancers, a sector group of Cefic speaking with one voice for the efficiency enhancers value chain. Fertilisers Efficiency Enhancers contributes to the scientific and policy debate and promotes, based on evidence, the agronomic and environmental benefits of nutrient enhancers in fertiliser applications to achieve the EU environmental targets.

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## Nitrogen Fertilizer Replacement Values of organic amendments: determination and prediction

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### Abstract

The nitrogen fertiliser replacement value (NFRV) quantifies the value of organic amendments as a nitrogen (N) fertiliser. This study aimed to (1) assess NFRVs of a range of organic amendments; (2) compare NFRVs based on equal N application with NFRVs based on equal N uptake; and (3) assess which product characteristics explain observed variation in NFRVs. A pot experiment was performed with spring wheat and a variety of organic amendments at two N application rates. NFRVs were calculated using two methods: (1) at equal N application rates by dividing the N uptake from an organic fertilizer by the N uptake from a mineral fertilizer at the same application rate and (2) at equal N uptake by comparing the N rates from mineral and organic fertilizer treatments needed to obtain the same plant N uptake. We show that calculating NFRVs at similar N application levels (method 1) consistently leads to an overestimation of NFRVs, because the N uptake response is subject to the law of diminishing returns. Consequently, N uptake from the organic fertilizer is in the linear part of the response curve while N uptake from the mineral fertilizer is in the non-linear part of the response curve. As it is unknown beforehand at which point N response curves start levelling off, calculating NFRVs at equal N uptake (method 2) is a better method for estimating NFRVs. Our study furthermore shows that short-term NFRVs can be explained by characteristics of organic fertilizers, namely total N, PMN and C:N ratio.

Review of whole-farm models for accurate nitrogen budgets

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## Abstract

Whole-farm models describe the economic functioning and nutrient flows on farms including their interaction with the environment, e.g. through greenhouse gas emissions emissions. They range from simple decision-support tools to complex dynamic process-based models.

The literature on whole-farm models in temperate climates was reviewed to identify gaps in knowledge, including development potential for the coupling with other models, within the context of the PREMIS project on primary farm data analysis and the Land-CRAFT center.

Web of Science and Scopus databases were accessed using relevant keywords. Articles related to whole-farm models were then selected and the main attributes of the articles used were noted. Articles found from the ones selected, or from personal communication, were also added using the snowball approach. This resulted in a database of 192 articles and 116 different models which described either the whole farm or parts of it. Dynamic process-based models were the most used, particularly the Integrated Farm System, (IFSM, Rotz et al., 2007) and the Agricultural Production Systems sIMulator, (APSIM, McCown et al., 1996). These were followed by life cycle assessment (LCA) analyses that adhered to international standards set by the International Organization for Standardization (ISO) (ISO 2006a and b)). Dairy and beef farms were the most studied farm types, with most studies published from the U.S.A. and Australia, followed by New Zealand and Canada. Once the different models have been reviewed, consideration will be given to the developments necessary to fill any gaps in the existing ones and feed into landscape-level models.

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## Revised estimation of faba bean $N_2$ fixation including belowground contribution

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### Abstract

Grain legumes (pulses) are interesting parts in sustainable crop rotations due to their ability of biologic nitrogen fixation (BNF). However, empirical results suggest that they are mostly N self-sufficient when balancing only the aboveground contribution. Throughout the literature there are often cited estimations of large additional N contribution from the belowground part (factor ~1.4). This mostly switches the N balance of faba bean from negative/neutral to surplus in contrast to only accounting the aboveground part, with consequences for the evaluation of rotational effects and/or risk of losses. A critical review of this commonly used factor based on empirical relations between belowground and aboveground N in faba bean plant material reveals an overestimation and leads to a smaller factor of 1.15 (derived from 42 original studies). Based on a comprehensive dataset (n=329) we found a mean N fixation of 43 kg/Mg faba been seed yield. In terms of N balances, a minimum fixation of 135 kg (2.76 Mg dry matter seed yield) is needed to reach a surplus. Compared to previously derived functional relationships, this assessment is much lower than other results including belowground contributions (Anglade et al., 2015; Palmero et al., 2022; Unkovich et al., 2010) and fits with own observations of economic optimal N rates from cropping system trials with and without legume pre-crops.

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## Assessing the Response of Five Oil Palm Genotypes to Nitrogen Sources and Drought Stress

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### Abstract

In Colombia, oil palm is the second-largest crop, covering nearly 600,000 hectares and producing approximately 1.8 million tons of oil annually. While past research has highlighted the positive impact of elevated ammonium concentrations on oil palm growth, the relationship between nitrogen form and drought stress remains a novel and understudied area. This study aims to fill this gap by investigating whether nitrogen sources exacerbate plant performance under drought or confer resilience. Seedlings from five oil palm cultivars were exposed to either ammonium or nitrate nutrition (15 mM) before subjecting them to drought stress. We assessed aboveground and underground biomass growth alongside physiological and biochemical responses.

Shoot biomass was significantly influenced by the type of nitrogen source used in the study, the water regimens, the genotype, and their interaction. Shoot biomass increased with ammonium even under drought, contrasting with nitrate. Despite drought stress, plants consistently preferred ammonium, leading to higher shoot biomass. Gas exchange and fluorescence parameters declined under drought stress regardless of genotype or nitrogen source, indicating the robustness of these responses.

Our research has significant practical implications for oil palm cultivation. Amid water stress, root amino acid content increased with both nitrogen sources, while in leaves, the trend was only evident with nitrate. Reducing sugars content surged under drought, favoring ammonium. Ammonium also enhanced phosphorus uptake compared to nitrate, with genotype-specific responses to drought. These findings provide valuable insights into strategies for enhancing oil palm resilience to drought through nitrogen management, which can be directly applied in the field.

## Changes in the root architecture of oil palm seedlings in response to nitrogen starvation

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### Abstract

The oil palm (Elaeis guineensis) is a key player in the global vegetable oil market, meeting about 35% of the world's demand. The expansion of oil palm plantations often involves reclaiming degraded soils with limited nutrient availability, notably nitrogen, which poses significant challenges to plant growth and productivity. Understanding how root systems adapt to nitrogen deficiency is crucial in this context. Using RhizoVision Explorer, this investigation aims to scrutinize root system architecture and its correlation with nitrogen availability across two commercially significant cultivars.

Correlations between eight root traits in oil palm seedlings and varying nitrogen treatments were observed, notably, a reduction in total root morphology, rotation angle, solidity, and hole characteristics under nitrogen deprivation, accompanied by increased surface angle frequency. The interactions observed in primary root morphology and hole size delineate differences between control and nitrogen-treated groups, particularly in the Coari × La Mé (C×LM) cultivar compared to the Deli × La Mé (D×LM) counterpart.

We found cultivar disparities, irrespective of nitrogen availability, on lateral root morphology, while nitrogen levels, independent of cultivar, impact inclined angle frequency. We also observe substantial disparities in growth and developmental parameters, encompassing root and shoot biomass, root-to-shoot ratio, and leaf emission numbers, between nitrogen-optimal and nitrogen-starved conditions. These findings underscore the critical role of nitrogen in determining root architecture and plant growth in oil palm, with pronounced effects, particularly in the C×LM cultivar during the nursery stage. This knowledge can be applied to optimize oil palm cultivation strategies, especially in nitrogen-deficient soils.

Importance of wheat variety for the interaction of mycorrhizal abundance and N transfer

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## Abstract

Mycorrhizas play vital roles in plant nutrient acquisition, performance and productivity in terrestrial ecosystems since soil nutrients, including $NH^{+4}$, NO3 and phosphorus, are translocated from mycorrhizal fungi to plants. However, not well understood, to what extent different wheat varieties associate with mycorrhizas and how this relationship may impact the N cycle in the soils. Within the EJP Soil project MaxRoot-C and in close cooperation with the H2020 project INVITE, we (i) compared the abundance of mycorrhizal structures in wheat roots between different varieties and environments, (ii) tested the relation between mycorrhizal abundance and grain yield, grain nitrogen content, and root production, nutrient uptake, N transfer and rhizodeposits up to 1 meter depth in the soil.

The study was conducted in the field seasons of 2021/2022 and 2022/2023 on ten modern winter wheat (Triticum Aestivum) varieties at four different European sites: Dotnuva LT, Eschikon CH, Freising DE, and Lleida ES. n the season 2021/2022 arbuscular, hyphal, and vesicular abundance ranged from 10-59%, 20-91%, and 0-3%, respectively, across all samples. Averaged across sites, the varieties varied by 8% and 18% in arbuscular and hyphal abundance, respectively. However, this did not translate into an increase in yield or nitrogen uptake as no significant relationships between mycorrhizal abundance at flowering and grain yield or grain nitrogen content were detected. In the season 2022/2023 selected 4 varieties showed significant differences in grain yield, total N content, root biomass and N turnover in the soil.

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## Nitrogen losses in legumes as pre-crop to winter wheat

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### Abstract

In intensive cropping systems, there is often a high risk for environmentally and climate-relevant nitrogen (N) losses in the form of nitrous oxide emissions and nitrate leaching, particularly when pre-crop and crop rotation effects are not adequately considered (Stoate et al. 2001). Legumes are known to have a high pre-crop value and can contribute to improving the N efficiency and greenhouse gas balance of crop rotations (Nemecek et al. 2008).

However, knowledge about nitrogen losses in legume cultivation under Central European conditions is limited, especially with regard to nitrous oxide emissions (Binacchi et al. 2023). For this reason, two similar field trials were set up in the north (Kiel) and south (Munich) of Germany in 2022/2023 as part of the "ISLAND" research project. In the field trial in southern Germany, the pre-crop effect of soybean and grass-clover-alfalfa is compared with non-fixing reference crops (spring wheat without and with N fertilization, field grass). In the following year, winter wheat is grown and fertilized with five N rates ranging from 0 to 320 kg $ha^{-1}$.

The investigations comprise soil and plant analyses, including yield formation, estimation of N2 fixation, measurement of soil nitrogen dynamics and nitrous oxide emissions, multispectral reflectance measurements as well as root investigations and greenhouse gas balances. The results of the first year show that spring wheat has the highest N loss potential of all investigated pre-crops, with increased soil mineral nitrogen stocks and cumulative direct nitrous oxide emissions.

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## Comparing remote and proximal platforms for crop N sensing in winter wheat

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### Abstract

Solutions are needed to reduce the negative environmental impacts of imprecise nitrogen (N) fertiliser use at different scales, including medium and small-scale production. Proximal and remote sensing information on crop N status has been shown to be valuable for improving N use efficiency at different scales (Raun et al., 2002; Sharma & Bali, 2017). In this study, commonly used sensors and methods are compared on the basis of their accuracy and robustness in assessing crop N in the field. The comparison of spectral information within five different categories of optical sensor platforms reflects market availability for use in both practice and research. The data for the case study were collected in 2019 in two experimental fields in north-eastern Switzerland, cultivated with winter wheat (T. aestivum). The equipment used consisted of a satellite platform, a fixed-wing unmanned aerial vehicle (UAV), a quadcopter UAV, a handheld field spectrometer and a tractor-mounted system. A power regression was used to compare the ground truth data of crop N content collected in the field with several spectral indices such as the Normalised Difference Red Edge (NDRE) (Argento et al. 2022). The main finding of this study was that the information obtained was comparable in quality and performance across different sensor levels and platforms. Thus, we conclude that sensor-based N status determination can contribute to broadly promote the improvement of N use efficiency, regardless of the available technology and sensing level.

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## Perennial grassland mixtures with clover and forbs reduce N dependency and environmental impacts without compromising yield

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### Abstract

Perennial grasslands utilize solar radiation during a larger part of the year than annual crops, thus producing higher biomass yields (Manevski et al., 2017). Biomass and protein produced in intensively managed grasslands can be used for feed, fiber and food, in the biobased economy (Jørgensen et al., 2022). Using legumes as N source in perennial grasslands may sustain a high and stable yield without high inputs of fertilizer and thus reduced associated emissions (Chojnacka et al., 2019).

In a field trial in Denmark, grass-clover-forb mixtures with increasing species diversity at 75 kg N $ha^{-1}$ $yr^{-1}$ were established in 2021 along with pure-stand perennial ryegrass plots with increasing fertilization. Aboveground biomass was harvested in 6x3 meter plots (3 cuts per year), and belowground investment to 1 meter depth was quantified in selected treatments. N2- fixation was determined by the $^{15}$N-isotope dilution method.

We found that increasing species richness to 6 species ensured a high and stable aboveground yield in the same range as the high-fertilized monocrop ryegrass, due to including the productive and complementary species red clover, white clover, plantain and chicory, together with perennial ryegrass and tall fescue. Increasing species richness to 18 species reduced biomass aboveground slightly and belowground dramatically.

We show how sustainable intensification of grassland biomass can be facilitated by legumes and functional diversity. The grass-legume-forb mixture with 6 species represented a sweet spot for high aboveground and belowground production at low N input.

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## Contrasting pre-crop effects on winter wheat nitrogen utilization

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### Abstract

Legumes are well-known for their beneficial pre-crop and rotational effects (Ditzler et al., 2021; Zhao et al., 2022). However, climate effects are rarely included in such analyses (Binacchi et al., 2023). Within the joint research project "ISLAND" environmental and agronomic effects of winter wheat after pulses and green manure legumes in contrast to cereal pre-crops is holistically investigated. At two sites in the north ("Kiel") and the south ("Munich") of Germany, similar field trials were established in 2022/2023 with nitrogen (N) rate experiments after contrasting pre-crops with comprehensive field data collection including weekly greenhouse gas measurements and spectral imaging as well as periodic plant and soil sampling. First results from the northern site show similar cumulative direct nitrous oxide emissions (1.5-1.79 kg $N_2O$-N $ha^{-1}$ in 327 days) but overall better agronomic performance of wheat after legumes. Economic optimal N rates were 23-44% lower, whereas grain yield was 11.0-12.7% higher. Therefore, N use efficiency was increased by 40-69% and radiation use efficiency by 11-12.5%. Furthermore, N balances showed less surplus after legumes. N-fertiliser savings of 56-108 kg from calcium ammonium nitrate can further reduce up to 396 kg $CO_2$-eq $ha^{-1}$ upstream emissions. However, challenges with establishment as well as utilization of the legume pre-crops has to be considered in a holistic evaluation as well.

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# NH3-Min project: What is the impact of the application techniques (injection fertilization CULTAN vs. area application) in terms of nitrogen use efficiency in winter wheat?

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## Abstract

Agriculture is facing multiple challenges- such as adaptation to climate change, providing high sustainable harvest yields but at the same time reducing ammonia emission and increasing nitrogen use efficiency. Environmentally friendly plant production sets one efficient use of fertilizers. The application solid or liquid fertilizers on the soil surface and - depending on fertilizer and crop type - in one or more shares is the most common form of fertilizer application. This form of nutrient application comes to the ideal of a placement that plant nutrients "direct and the root" not very close. The CULTAN (Controlled Uptake Long Term Ammonium Nutrition) is a technique where ammonium based fertilizer injected inside depots of the soil. The fertilizer is applied in only one rather than the conventional 2 to 3 doses which is supposed to inhibit nitrification from bacteria due to the high pH and salinity.

The research project NH3-Min, we conducted a multi-plot field experiment on winter wheat, set up at 10 sites across Germany. In three of the sites, we fertilized plots also with the "Controlled Uptake Long-Term Ammonia Nutrition (CULTAN)" method, where liquid ammonium-based fertilizer is injected only once at the beginning of the growing season at high concentration into depots near the root zone, as opposed to usually three fertilizer applications throughout the growing season. We measured soil mineral nitrogen content in the CULTAN treatment four times during the growing season, each time directly in the depot, between the depots, and between rows. Additionally, we monitored soil mineral nitrogen dynamics, pH, weather conditions and various plant parameters, such as yield, biomass and protein content.

Using our data, we will compare yield, dry protein and nitrogen use efficiency of urea ammonium sulfate injections (CULTAN) with conventional solid urea ammonium sulfate surface application. Preliminary results show that CULTAN injection resulted ammonium was completely absorbed by the plants during the first two to three months after application as observed in soil mineral N dynamics. No significant difference in yield was observed between the different fertilizer treatments, although at one site a decrease in grain dry protein content was found with the CULTAN treatment. The final aim is to assess the suitability of the CULTAN method increasing nitrogen use efficiency, yield and dry protein vs. the area application.

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# Assessing nitrogen and water response in wheat genotypes combining hyperspectral and thermal sensors

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## Abstract

Nitrogen (N) and water are the main limiting factors in global agricultural production (Mueller et al., 2012). Enhancement of N and water use efficiency simultaneously may provide advantages over-optimization of both inputs separately (Quemada and Gabriel, 2016). In this study, two winter wheat (Triticum aestivum L.) genotypes (Cellule and Nogal) were explored to determine their nutritional and water status through remote sensing in two field experiments conducted in central Spain during 2018-2021. The nitrogen nutrition index (NNI) at flowering and the grain yield (GY) and grain N concentration (GNC) at harvest were determined. The canopy reflectance (400 – 900 nm) measured with a handheld spectroradiometer was used to calculate vegetation indices (VIs) and to implement a radiative transfer model (RTM). A thermal camera was used to determine the water deficit index (WDI) and canopy-air temperature difference ($T_c$-$T_a$). The results showed that predicted chlorophyll by RTM and VIs built with the red-edge bands obtained the best agreement with NNI ($R^2 \geq 0.60$ in both genotypes) and GNC ($R^2 \geq 0.45$ and 0.38 in Cellule and Nogal respectively). For GY, VIs combining near-infrared (NIR) / visible and NIR / red-edge bands showed the highest accuracy ($R^2 \geq 0.74$ in Cellule and $R^2 \geq 0.56$ in Nogal). The WDI and $T_c$-$T_a$ demonstrated that Cellule (the more drought-resistant genotype) was less water-stressed than Nogal. Finally, a new methodology that combines optical and thermal data improved the assessment of agronomic parameters, showing its potential for conducting irrigation and N fertilization management simultaneously (Raya-Sereno et al., 2024).

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## Canopy nitrogen index based on Remote sensing and machine learning

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## Abstract

N (Nitrogen) is considered as a mineral nutrient for plant growth and production, as it is directly related to photosynthesis, protein metabolism, carbon and N synthesis processes. Traditional N management within a field is often based on experience or standard recommendations tests which could lead to inaccurate N fertilizer use. Using remote sensing technology, can improve the accuracy of the estimation of canopy N content, especially in the context of precision management (Chlingaryan et al., 2018). However, even in this case the contemporary presence of water and nitrogen stress on crop might hamper the accuracy of remote estimations.

The objective of this study is to develop an improved Canopy Nitrogen Index (CNI) estimation model that accounts for water and nitrogen stress. In addition, the CNI is then used along with machine learning models at the key growth stages to determine canopy N needs. For this study, handheld spectroradiometer, drones and satellite data are used.

The expected result of this research is to develop an algorithm for measuring N requirements with water/biomass. Through a comparative analysis of the classic and improved CNI, the study seeks to establish a new benchmark in precision agriculture, thereby improving N management strategies while contributing to more sustainable agricultural practices.

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## Does soil sample conservation method impact on ammonium, nitrate and total mineral nitrogen measurements?

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### Abstract

Scientific literature for mineral soil nitrogen content (ammonium and nitrate) measurements usually differs regarding the chosen soil sample conservation method (fresh, frozen or air- dry) before soil extraction and analysis. In addition, most of the commonly used methodologies focus on the definition of the analysis processes, regardless of the previous sample conservation methodology. With the aim to fill this gap, we performed an analysis of the conservation method effect on the nitrate, ammonium content in frozen or air-dried samples, comparing the results with direct fresh extraction. Moreover, the effects of additional soil parameters, such as soil texture, organic matter content or mineral nitrogen content range were also studied. The results showed that both, frozen and air drying soil samples, were capable of reliably preserve the N content of soil samples in most cases.

However, some ammonium losses may occur in frozen samples when a high N content (>30ppm) was present. It was also observed that air-dried soil samples can reduce the soil nitrate and increase ammonium content in samples with a high N content. It was also observed that significant amounts of organic matter in soil can alter the mineral N measured depending on the conservation method chosen. On the other hand, the soil texture presented small effects on the mineral N measurements. In any case, a broader range of soils should be further tested to confirm our findings.

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## Green manure in vegetable crop rotation reduces the need of mineral N fertilization

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### Abstract

Efficient vegetable production in open field is largely dependent on mineral fertilizers. Intensive tillage, plant cover only part of the year and nutrient-rich plant residues increase the risk for nutrient leaching from vegetable fields. Our research aimed to enhance the sustainability of plant nutrition in field vegetable production by studying the effects of soil amendments and green manure on crop growth, nitrogen availability and soil physics. A three-year field experiment was conducted in Piikkiö in southwest Finland. Soil amendment treatments in 2021 were the use of wood fibre (nutrient-poor zero fibre or zero-fibre+chicken manure product) and one-year green manure (mixture of vetches, cereal crops and Italian ryegrass). Onion and white cabbage were grown on the plots in 2022 and 2023, respectively, with three N fertilization rates to explore the effect of the preceding fibre or green manure treatment on the N fertilizer demand of the vegetable crops.

Results show that the nutrient-poor zero fibre did not interfere with the growth or nitrogen uptake of vegetables cultivated in the following years. Green manure improved the N availability to the onion crop in 2022, but no clear effects were observed in white cabbage in 2023. We conclude that green manure could be utilized more commonly in the vegetable production systems in open field, when aiming to reduce the need of mineral N fertilizers and increasing the biodiversity in the farm level.

# Nitrification inhibitor-induced rhizosphere ammonia-oxidizing microbe changes related to maize NUE

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## Abstract

Nitrification inhibitors (NI) are usually used as effective tools to reduce nitrous oxide emissions and increase nitrogen (N) nutrient efficiency, which have the potential to increase crop yield. The rhizosphere is the core of plant root-soil-microbiome connecting aboveground with underground organisms. Rhizosphere microorganisms play a vital role in plant nutrient uptake and use efficiency, especially N. But it remains unknown how NI influence rhizosphere microbes to realize N use efficiency (NUE) improvement. The present study use maize as the target plant and employ pot experiment with $^{15}N$, and quantitative real-time PCR (qPCR) to identify the N-related rhizosphere microbes responding to the NI application and investigate how the specific microbes contributed to maize NUE. The present results showed that, in comparison to N fertilizer-alone treatment, NI application obviously increase maize NUE by 44.6%, and simultaneously increase plant labeled N derived from fertilizer ($^{15}$Ndff) and soil (Ndfs). Results demonstrated that NI significantly affected key functional microorganisms participating N transformation process at the root-soil interface, especially ammonia-oxidizing archaea (AOA) and bacteria (AOB). The results showed that NI application promoted N accumulation and NUE of maize by stimulating AOA and decreasing AOB amoA gene abundance. The abundance of AOA was positively and significantly correlated with the effect of maize rhizosphere on fertilizer N enrichment. This research innovatively unravel the mechanisms underpinning the plant root-soil-microbiome interactions in response to NI application and the present results would provide valuable information for better N management strategies to reduce N losses and improve N use efficiency.

# TerraZo - free application map creation and deployment based on field trials

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## Abstract

TerraZo, developed by Josephinum Research, is a web application designed to facilitate site-specific fertilization for farmers without requiring high acquisition costs for new equipment or expensive software. Based on Sentinel 2 satellite data and field trials, vegetation indices are calculated, and fertilizer recommendations for each subarea are generated using models. The application maps that are generated can be easily exported and imported into compatible tractor terminals, enabling seamless utilization in the field. Alternatively, smartphones or tablets can be used for site-specific fertilizer application. Result is that variable and site-specific N-fertilization leads to savings in inputs and tailored plant nutrition. In addition, site-specific fertilization ensures a balanced N-budget, higher N-efficiency, and lower greenhouse gas emissions. Nevertheless, the creation of application maps requires not only technical expertise but also the incorporation of agronomic and location-specific characteristics of the fields. Both aspects are considered to simplify the technical barriers for the user and support them in site-specific fertilization through proposed fertilizer quantities. It is important that the user can customize all suggestions to accommodate their personal preferences and experiences. Another important point is that when we able to established such a system on a wide scale, new knowledge is transferred directly to the point of application. This can lead to widespread adoption and implementation of site-specific fertilization practices. By incorporating advanced technologies and data-driven approaches, practice and science can benefit from each other and more informed nutrient management decisions can be made.

## Predicting the Nitrogen Content of Mediterranean Forage Crops: a Remote Sensing Approach

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### Abstract

Remote sensing with Unmanned Aerial Systems (UAS) can potentially provide information on the Nitrogen content of forage crops with sufficient accuracy to support farmers' decisions on livestock feeding (Cammarano et al., 2011). We developed an algorithm based on the Canopy Chlorophyll Content Index ((CCCI; Barnes et al., 2000) and the Canopy Nutrition Index (CNI) to predict the N content of Mediterranean rainfed forage canopies. A two-year dataset was generated from a field experiment within the SYSTEMIC project on four forage legumes and grasses, as pure stands or mixtures, under two mowing frequencies, to calculate the CNI from plant N concentration and aboveground biomass. Multispectral data from an UAS were collected to calculate CCCI. The canopy N content was then predicted from the relationship between CNI and CCCI. A good agreement ($R^2$=0.80, RMSE=1.99 g $m^{-2}$, d=0.93; P<0.001) between the predicted and observed N canopy content (g $m^{-2}$ of N) was observed. The estimation of canopy N content was better under high cover of annual ryegrass (RMSE=1.78 g $m^{-2}$, index of agreement=0.95) and in frequently mown plots (RMSE=1.52, d=0.95). The agreement improved below a threshold of 13.3 g $m^{-2}$. The study showed that the N content of forage crops can be predicted from the remote-sensed CCCI starting from N dilution curves. The prediction accuracy is influenced by the mowing frequency and the species relative abundance, and it is limited above a threshold corresponding to high biomass. The results provide a basis for a real-time field estimation of grassland forage quality.

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## Is the use of nitrogen transformation inhibitors a feasible and safe measure to achieve climate and environmental goals in agriculture?

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### Abstract

The usage of urease and nitrification inhibitors for nitrogen transformation manipulation are increasingly propagated to reduce ammonia and nitrous oxide emissions from the application of nitrogen fertilizers. Their use may become even more important after the year 2030 when the agricultural sector will be obliged to make more significant contributions to the ambitious European climate targets. But potential risks of large-scale application of these inhibitors for human health and ecosystems have not yet been sufficiently investigated. In addition, the data on the fate of the substances in the environment is patchy and the specific effectiveness of various active ingredients has not yet been sufficiently researched.

These uncertainties have so far only partially been considered in the legal regulations at EU and national level. This can be seen, for example, in the fact that substances such as Nitrapyrin, 1,2,4 Triazole or 2 NPT are authorized as inhibitors in the EU, but would with high probability not be approved under the EU-regulation for plant protection products. This is the case although the application to the open environment as well as the quantities applied are similar for inhibitors and plant protection products.

The paper will report estimated emission reduction potentials of inhibitors, highlight possible risks to the environment and health, discuss the scientific analysis of efficacy and critical review the authorization procedures. Finally, we make recommendations on how approval procedures can be improved and corresponding risks reduced.

## Economic Evaluation of N Use from Organic and Inorganic fertilizer on the Yield of Kenaf in Nigeria

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### Abstract

This study was carried out to economically evaluate the Nitrogen use efficiency from organic and inorganic fertilizer on the growth and yield of kenaf fibre and seed production. The growth performances were carried out with the application of varying Organic and inorganic fertilizer applied at 0, 70, 100, 130, and 160 kg N ha$^{-1}$. Field trials were conducted with the aim of determining the growth and yield performance of kenaf and most economically feasible in the treatment used. Data obtained were subjected to statistical and inferential analyses such as analysis of variance (ANOVA) at **α** 0.05 and profitability analysis. The ANOVA result shows that highest average growth rate value was obtained under 160 kg N/ha at 4-6 (16.31 g/plant), 6-8 (21.04 g/plant) and 8-10 (19.84 g/plant) weeks after sowing while there was no significant difference in the effect of N fertilizer at rate 160 and 130 kg N/ha on average growth rate (10.18 and 10.17 g/plant) respectively at 10-12 weeks after sowing. The results of the gross margin analysis shows that highest net benefits ₦2,974,100 and ₦3,041,600 derived from core and bast fibre were achieved under the rate of 130 kg N/ha for both organic and inorganic fertilized used, while highest net benefit of ₦2,827,600 and marginal net benefit of ₦733,500 were realized from inorganic fertilized field at 130 kgN/ha. However, to avoid excessive exploration of the Nitrogen use, Nitrogen use of 130 kg N ha$^{-1}$ was therefore recommended for use due to its high marginal benefit.

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# Potential for microbial nitrogen-cycling in biochar, fertilizer and manure amended soils: A study from smallholder maize cropping fields in Kenya and South Africa

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## Abstract

Biochar can improve crop yield by 25% in tropical soils as compared to temperate soils where responses are negligible (Jeffery et al., 2017), but the underlying mechanisms are not clear. The increased soil fertility is potentially explained by modification of soil nitrogen (N) cycling. Therefore, we examined the effect of biochar, mineral fertilizer and manure application on the genetic potential for different N-transforming process by quantifying genes involved in ammonia oxidation (amoA), denitrification (nirK, nirS and nosZI), nitrate ammonification (nrfA), and N-fixation (nifH) in soil under maize cropping. The treatments included: control, fertilizer, manure, 3 t ha−1 biochar, 6 t ha−1 biochar, fertilizer + 3 t ha−1 biochar, manure + 3 t ha−1 biochar, and manure + 6 t ha−1 biochar. These treatments were replicated at three sites, Kwale and Embu in Kenya, and Okhahlamba in South Africa. Based on the availability of feedstock, coconut shell biochar was applied in Kwale, and maize cob biochar in Embu and Okhahlamba. Preliminary results show that the variations in N cycling genes among the treatments were more pronounced in Kwale possibly due to the higher soil pH than in the other two sites. Fertilizer generally increased the potential for bacterial ammonia oxidation in bulk and rhizosphere soils, regardless of biochar application, whereas the potential for the anaerobic processes nitrate ammonification and denitrification were generally highest in the bulk soil of Kwale in manure and manure + biochar treatments. Compared to the other processes, bacterial ammonia oxidation had the strongest positive correlation with maize yield. This study further improves our understanding of biochar functions for increased fertility in tropical soils.

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## Optimizing Nitrogenous Fertilizer Management for Enhanced Rice Growth and Yield in an Alfisols

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### Abstract

Global food security is threatened by climate change and population gloat. It has become imperative to produce crops through sustainable resource management practices that will give higher yield while ensuring a safer environment. This study examines the impact of nitrogenous fertilizer management on rice growth and yield components in an Alfisols. Two different fertilizer management strategies, namely F1 (Granulated NPK + Granulated Urea) and F2 (Granulated NPK + Urea super granule) were evaluated in combination with various placement methods (P1: Side or band placement, P2: Broadcasting placement, P3: Deep placement). The study assessed plant height, number of tillers per hill, and yield parameters including percentage number of unfilled grains (NO: U-FG), 1000-grain weight, and paddy yield at different growth stages. The results showed that the F1 had a range increase of 3 to 7% plant height at all the measurement interval which differed significantly from the F2 irrespective of the placement method. However, the F1P1 differed significantly from the F2 at all the placement methods with a range increase of 5.5 to 15.4%. In terms of yield component parameters, even though there was no significant difference between the fertilizer management at different placement intervals, the F1 had the highest number of panicles at P1, number of grains per panicle at P2, and number of filled grains at P3. The least number of unfilled grains were observed in F1P3, while the F2P3 had the highest number of 1000GW with a range increase of 3.74 to 8.84% relative to the other treatment combinations. The highest grain yield was mostly obtained in F1 treatments combinations which did not differ significantly from the F2 treatment combinations. This study highlights the importance of nitrogenous fertilizer management in influencing rice growth characteristics and provides insights for optimizing fertilizer application strategies to enhance rice production in sandy loam soil conditions. The findings contribute to the ongoing efforts aimed at improving agricultural practices for sustainable rice cultivation.

Keywords: Fertilizer management, fertilizer placement methods, growth, grain yield

## Crop improvement for Nitrogen Use Efficiency in rice

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### Abstract

Rice is the 3rd most cultivated crop globally with a huge germplasm and genomic resources, hence an ideal target crop for improvement of NUE. We characterized the phenotype for NUE with urea and nitrate and showed that late-germinating, long duration rice varieties have higher NUE than the early-germinating, short duration varieties. We generated N-responsive transcriptomes in Japonica and in contrasting Indica varieties of rice, to identify the N-responsive genes/pathways associated with yield and therefore NUE. Hierarchical shortlisting of NUE-related genes using phenotypic-association, quantitative trait loci co-localization, functional annotation and protein–protein interactions revealed many candidate genes/pathways involved in NUE. They include many transporters, transcription factors (TFs), MicroRNAs (miRNAs), kinases, and phosphatases. Experimental validation in two contrasting genotypes revealed that high NUE rice shows better photosynthetic performance, transpiration efficiency and internal water-use efficiency relative to low NUE rice. All these processes were also affected in the G-protein **α** mutant in Japonica rice with higher NUE, revealing the role of G-protein signalling in regulating NUE. We found genotype-dependent regulation of many transporters, transcription factors and miRNAs apart from differential post-translational modifications hitherto unlinked to NUE, in contrasting genotypes. Field evaluation with urea revealed that differential involvement of transporters and TFs contribute to better urea uptake, translocation, utilization, flowering and yield for high NUE. Over 70% of the rice N-responsive genes contain G-quadruplex sequences (G4Qs), indicating predominantly epigenetic regulation, but only 17% of the NUE-related genes contained G4Qs, making them more amenable for genetic improvement. We are currently validating them by genome-editing.

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## 2.2 Session 2: Reducing nitrogen losses

## National tool for estimating transport and reduction of nitrogen from agriculture

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### Abstract

Nitrogen, in the form of nitrate, may undergo denitrification during transport in the subsurface or in surface waters. The reduction is caused by natural processes and shows large spatial variation. Spatial variability means that the effect of nitrogen mitigation measures will also vary spatially, with highest effect in areas with the lowest degree of denitrification.

A national nitrogen model for Denmark has been developed linking national models describing the various part of the terrestrial nitrogen cycle (Højberg et al., 2021). Leaching from the root zone is based on the statistical model NLES (Børgesen et al., 2020).

Groundwater transport, including drainage and nitrogen reduction in the subsurface, is based on a national hydrological model combined with a description of geochemical subsurface conditions. Denitrification in surface water systems is described by individual statistical models. The model complex is used to calculate nitrogen transport and reduction from the root zone to the sea, and to calculate the so-called national nitrogen retention maps, displaying the geographic variation in nitrate reduction.

Although the nitrogen load to the sea has been almost halved in Denmark, further abatement is required calling for optimal measures placed on optimal locations (Hansen et al., 2024). An important aspect in the current development of the national nitrogen model is thus to analyse the scale at which nitrate retention can be estimated with acceptable certainty. The paper will provide an overview of the entire modelling framework and discuss the relation between model results, scale and associated uncertainty.

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## The Nitrogen Budget and Footprint Trend for Agro-Products in Malawi

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### Abstract

Agriculture is predominantly the paramount cause of N footprint in most developing countries and Malawi is not an exceptional. N-footprint studies are of tremendous relevance to both improve agriculture N management which guarantees adequate output and attain environmental sustainability. Unfortunately, there are very limited studies in Malawi, which attempts to identify, estimate, and contributes toward nitrogen management. To fill the gap, the paper provides the first country specific Nitrogen footprint (NF) of Malawi using the novel web-based tool called N-calculator[1]. We developed the Virtual N Factors and estimated the NF from agriculture production in Malawi from 1961 to 2021[1]. Furthermore, top-down calculation was employed to estimate the total N-input (SNF, BNF, ANM, SNF) for 15 years (2002-2016) for Malawi, due data limitation[2]. The crop product considered in this study include Maize, rice, starchy roots, fruit, and vegetables while livestock include chicken (eggs as a separate category), cattle (beef and dairy) small ruminant (goats, pigs). The average food N footprint of Malawi was 16 Kg $N/cap^{-1}/yr^{-1}$ whereby 12 Kg $N/cap^{-1}/yr^{-1}$ was virtual N footprint and 3 Kg $N/cap^{-1}/yr^{-1}$ was consumption footprint. The results displayed that rice and maize have the highest virtual N factor in the category of crop, while beef and milk are the highest in the animal product category. Further studies are therefore required to assess how international trade influence the perturbation of nitrogen budget in Malawi and link the footprint to the associated environmental effects.

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# BCC – a fast and simple tool to estimate CO2eq savings of fertilizer additives

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## Abstract

After application of nitrogen (N) containing organic and mineral fertilizers N losses in form of ammonia (NH3) and nitrous oxide (N2O) into the atmosphere as well as nitrate (NO3) leaching out of the root horizon into deeper soil layers and groundwater can occur. All these N losses result in (direct and indirect) N2O emissions. Compared to carbon dioxide (CO2), N2O has a nearly 300 times higher global warming potential. So N2O can be translate into CO2-equivalents (CO2eq). BCC is a fast and simple tool to calculate CO2eq emissions from N applications. It is based on scientific proven emissions factors for the different N losses from different N fertilizers under different soil and weather conditions as well as reduction factors for different management measures. It allows to compare different fertilization systems (e.g. N fertilizers without versus with fertilizer additive like e.g. nitrification inhibitors) and so to calculate e.g. CO2eq savings. It is an easy tool for N fertilizer producers/distributers, farmers and authorities to get a quick estimation of the CO2eq amount of the application of N fertilizers in the field. Together with other tools the product carbon footprint (PCF) of a crop production system (e.g. per unit crop yield) can be estimated.

## Set-aside land as a target measure for reducing N leaching losses

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### Abstract

The agricultural sector is facing increasing demands to reduce its nitrogen (N) losses via leaching and gaseous emissions. While N concentrations in Denmark's watercourses have been significantly reduced since the implementation of various control regulations, further improvements are required. The obligatory non-productive areas in the recent CAP reform and a new spatially targeted measures for N-load reductions to be introduced by the Danish Parliament in the near future both include set-aside land, where a portion of the land is kept fallow and not used for crop production. Such set-aside land can take-up residual N from previous crops, and as no soil tillage and no N fertilisers are applied to these areas, the amounts N loads in catchments or sensitive areas are reduced. There is, however, a lack of understanding about the mitigation potential of set-aside land, and how it should be managed. Especially, knowledge about the interactions between different species grown on such set- aside land and environmental conditions (soil types, climate) and how they reduce N leaching loads is lacking. To address this, field experiments were set up in two contrasting sites within Denmark with different types of set-aside land, including grass, grass in mixture with legumes, crucifers, and other flowers to increase the pollinator diversity. Leaching from these were compared to a spring barley crop with the common mitigation measure of a catch crop. Leaching differed between the different species and species combinations, as well as between the two sites. Experiments are ongoing to shed further light on this.

## Towards zero carbon: Benchmarking the nitrous oxide emissions from coffee and cocoa plantations

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### Abstract

To reduce environmental burdens from the food production system, it is essential to benchmark the current greenhouse gas (GHG) emissions from coffee and cocoa plantations. Tracking progress in reducing these emissions is of fundamental importance to shift towards environmentally sustainable production, especially because coffee and cocoa play a crucial role in the incomes and livelihoods of millions of smallholders worldwide, contributing to food security. Particular attention must be paid to the nitrogen (N) cycle, especially regarding the use of N fertilizer. After N fertilization, large emissions of nitrous oxide ($N_2O$), a potent GHG, occur. Coffee typically utilizes high doses of N fertilizers, ranging from 200 to 600 kg $ha^{-1}$ of N. However, coffee exhibits low N use efficiency and may result in high N losses as $N_2O$, with few studies evaluating these losses. Much less is known about GHG emissions from soils with cocoa, especially $N_2O$. Therefore, we are benchmarking GHG emissions as part of a broader initiative to reduce the carbon footprint and safeguard soil health in coffee and cocoa production systems worldwide, with a special focus on defining the baseline emissions of $N_2O$. The specific goal is to understand the extent to which different management practices, including the application of organic and inorganic fertilizers, affect $N_2O$ emissions in coffee farms in Colombia, Mexico, and Zambia, and cocoa plantations in Ecuador and Ivory Coast. The results will be used to derive new emission factors and sustainability indicators for coffee and cocoa production.

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## Nitrogen balance of annual and perennial cropping systems is described by process-based models: A case study with Daisy and DSSAT models

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### Abstract

Simulating long-term cropping systems is important to study strategic agro-economic scenarios and associated nitrogen (N) flows and environmental risks such as nitrate leaching (Timlin et al., 2024). Process based models have advantages regarding detailed description of the N biogeochemical cycle, but also disadvantages related to parameters uncertainties and error propagations. We compared Daisy and DSSAT for simulating major N flows of different cropping systems over ten years, including conventional monocultures (maize, triticale and grain rotation), optimized rotation for large biomass production and perennial systems (highly fertilized festulolium and not fertilized grass-legume mixture).

Along each model structure, parameterization and calibration, both models predicted aboveground biomass (RMSE< 3 Mg ha$^{-1}$; nRMSE<33%) and N uptake (RMSE<53Kg ha$^{-1}$; nRMSE<39%) mostly acceptable for conventional and optimized rotation systems, but accuracy was lower for the perennial systems (biomass nRMSE<54%; N uptake nRMSE<79%). Soil profile water contents (nRMSE<23%) and drainage were predicted well for both models. Percolation-weighted concentration estimated nitrate leaching was comparable between the two models (R2>0.75). Stimulated nitrate leaching cumulative over 10 years was also comparable, except for triticale. Ensembled nitrate leaching reduced the uncertainty and increased the accuracy of the predicted values.

In conclusion, both models reflected the variability in the field N balance (inputs minus outputs) across all seasons - an important finding that supports the use of double-model estimates rather than reliance on single models. The study also points on the need for model calibration dedicated data on perennial systems in relation to grass re-growth after defoliation.

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## A $CO_2$-Guided Approach to Estimate the Effect of Soil Management Practices on Nitrogen Mineralisation

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### Abstract

Quantifying short-term effects of agronomic management practices on soil organic nitrogen (SON) mineralisation is necessary to promote sustainable nitrogen use. However, existing modelling approaches often encounter challenges due to the lack of localised datasets or methodologies for site-specific model calibration. We investigate a cost-effective method to assess temporal dynamics of SON mineralisation in arable fields. This method involves in situ measurements of the soil $CO_2$-flux using a steady-state through-flow chamber (Pumpanen et al. 2004). Simultaneously, soil moisture content (0-30 cm) and soil temperature (0-5 cm) are measured to consider their interactions with mineralisation.

Assuming negligible $CO_2$-release from root respiration, liming or fertilisation, these measurements allow the assessment of the temporal evolution of soil organic matter (SOM) mineralisation in field conditions. Finally, this approach permits a theoretical quantification of SON mineralisation taking into account inter alia the C:N ratio of the SOM.

Short-term (7-14 days) changes in SON mineralisation following tillage practices and irrigation were estimated in maize, potatoes and leek crops. To validate these estimates, soil mineral N content (0-30 cm) was measured on the first day following tillage or irrigation and on the last day of $CO_2$-flux measurement.

The aim is to create a robust dataset, enabling in-field estimations of the impact of aeration (tillage) and water availability (irrigation) on SON mineralisation across diverse soil textures, cropping systems and meteorological conditions. This dataset will be used to modify and calibrate an N balance model that will be integrated into a farmers' decision support tool for N management.

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## Nitrogen bank strategy of fertilisation increases grain yield as well as nitrous oxide emissions

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### Abstract

Estimation of nitrogen (N) requirement in dryland grain crops in southern Australia is notoriously difficult because of highly variable seasonal rainfall, which leads to under-fertilisation and a significant yield gap. Growers use a range of methods for deciding N fertiliser application rate, such as the Yield Prophet® (YP) decision support system (Hochman et al., 2009). In contrast, the N bank (NB) strategy sets an optimum N supply target for an environment which does not vary seasonally (Meier et al., 2021). We monitored nitrous oxide (N2O) emission in a field experiment in Victoria designed to compare the long-term agronomic performance of the different decision-making systems against the national average (NA) application of 45 kg fertiliser-N/ha and a control (NIL). The NB strategy applied 125 kg fertiliser-N/ha to a wheat crop, whilst YP only applied 16 kg fertiliser-N/ha due to high starting soil mineral N and low growing season rainfall up to the time of decision making. The NB strategy was able to achieve the highest grain yield (7.1 t/ha), followed by YP (6.3 t/ha), NA (5.8 t/ha) and NIL (4.9 t/ha) treatments ($P<0.001$). Although the NB strategy increased wheat yield compared to the NA treatment, it also led to more than double the N2O emission during the season (1.7 c.f. 0.8 kg N2O-N/ha). N2O emissions in the YP and NIL treatments were similar to NA. In 2023, the NB strategy was successful in closing the N related yield gap by applying more fertiliser N, but this came at the cost of higher fertiliser N loss as N2O.

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## Impact of sectoral fuel consumption and energy utilization on $NO_x$ and $N_2O$ emissions

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### Abstract

Anthropogenic reactive nitrogen in the ecosystem is the by-product of energy consumption and food production, which are two vital civilization activities. In this study, $NO_X$ (as $NO_2$) and $N_2O$ emissions due to energy consumption were calculated using Türkiye's publicly available official data, for the first time. Fuel consumption records from five sectors, i.e., industry, transportation, agriculture (machinery), residential (including services) and power generation was collected between 1970 to 2016. $NO_X$ emissions increased 6.6-fold and $N_2O$ emissions increased 1.8-fold nationally over forty-six years. The highest change in $NO_X$ and $N_2O$ emissions was observed in power generation sector with a 30-fold and 24-fold increase, respectively. It is followed by transportation with 8.5-fold increase in $NO_X$ and 7.4-fold increase in $N_2O$ emissions. Transportation dominated the other sectors in terms of $NO_X$ emissions whereas residential dominated the others in terms of $N_2O$ emissions although the relative share of these two sectors varied in total. $NO_X$ and $N_2O$ emissions increased in all sectors except the residential $N_2O$ emissions which decreased 0.6-fold. Regarding socioeconomic factors, per capita $NO_X$ emissions increased three times whereas emission/GDP ratio decreased seven times indicating a cleaner added value for GDP of the country. Per capita $N_2O$ emissions decreased 20%, emission/GDP ratio decreased twenty-six times representing much less $N_2O$ emission per unit GDP increase. Moderate, positive and statistically significant correlation was found between $NO_X$ and $N_2O$ emissions from power generation and transportation sectors and human development index (HDI). The correlation between HDI and residential $N_2O$ emissions was moderate, negative and statistically significant.

# Modelling to interpret the systems aspects affecting the efficacy of enhanced- efficiency fertilisers

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## Abstract

Enhanced-efficiency fertilisers (EEFs) have the potential to reduce nitrogen (N) loss and increase crop yield. However, field experiments across a wide range of agricultural systems globally have resulted in variable outcomes. Raising the questions: Why do EEFs sometimes fall short of their promise? and What drives their efficacy?

Here we present agricultural systems modelling using the APSIM model (https://www.apsim.info/) to uncover how interacting soil, crop, climate, and management factors lead to variable results. Drawing on the results of thousands of virtual EEF response trials performed in sugarcane production systems we identify three prerequisite conditions that explain conditions under which yield benefits and N loss reductions can be expected (Verburg et al., 2022): (1) sufficient longevity of protection of the fertiliser N, (2) occurrence of an N loss event during this period of protection and before the N is taken up by the crop, and (3) the crop being responsive to the fertiliser N.

We present the prerequisite conditions as a framework to determine the likely outcomes of EEF use and reflect on its application in different agricultural systems, including maize systems in the US Midwest. These case studies illustrate the interplay between the three prerequisite conditions, but also highlight that considerations for N loss reductions depend on the N loss pathway.

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## Acknowledgements

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## Loss of organic nitrogen from agricultural fields and catchments

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### Abstract

Worldwide, farming activities exert strong impacts on the amount and molecular composition of dissolved organic matter (DOM), which constitutes an important vector of organic nitrogen (ON) transport from soils to the aquatic environment (Graeber et al., 2015). In Denmark, stream data from the national monitoring programmed NOVANA shows that total ON today amounts to nearly 20 % of the annual N loading to Danish coastal waters. In a newly started research project 'orgANiC' we will investigate the loss and fate of ON forms in five smaller agricultural so-called LOOP catchments in Denmark (Petersen et al., 2021), in fields within the national pesticide monitoring programme, and longer-term experimental plots at three Danish agricultural research stations. In our project we will measure dissolved ON (DON) and dissolved organic matter (DOM) in soil water, groundwater, tile drainage water, surface runoff and streams by means of utilizing both indirect (total N minus inorganic N) and direct analysis of DON (size exclusion chromatography: SEC). Moreover, we will characterize DOM composition utilizing SEC as well as fluorescence spectroscopy and conduct controlled laboratory experiments to unravel the bioavailability and fate of DON in freshwater (Graeber et al., 2018). The loss of particulate ON (PON) will also be monitored in tile drainage water, surface runoff and streams as these hydrological paths are believed to be of increasing importance with the observed increase in extreme weather conditions. In the presentation we will share our current insights into ON measurements as well as our plans for the new 'orgANiC' project.

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Inefficient irrigation and fertilization as drivers of N loss: lessons from the Po Plain droughts

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## Abstract

Agricultural practices have significantly modified the water and nitrogen (N) cycles, and climate-related droughts are expected to further amplify the effects of anthropogenic pressures on hydrological and biogeochemical processes. These issues were explored in the Chiese River watershed, within the Po Plain, Italy, where strong, tight interactions link soil, aquifer, and the river. This watershed can be taken as a compelling case for examining the consequences of conventional irrigation techniques on N loss and contamination of the hydrosphere within the framework of water scarcity. During summer, flood irrigation is sustained by groundwater withdrawal as drought reduces river discharge. The permeable and highly fertilized soils favor the percolation of nitrate ($NO3^-$) to the groundwater, where it accumulates due to limited losses via denitrification. In the Chiese River watershed, the N surplus from Soil System Budget calculations decreased by 43% in 20 years but $NO3^-$ concentrations in groundwater remained constantly high (up to 98.0 mg $NO3^-$ $L^{-1}$). The river gains groundwater and the diffuse N pollution promotes river contamination, approaching 32.2 mg $NO3^-$ $L^{-1}$. Results suggest how fertilization exceeds crops uptake, and contaminates groundwater and surface waters, leading to the violation of both Nitrate and Water Framework directives and eutrophication issues. There is an urgent need to adopt in the Po Plain more efficient irrigation and fertilization practices to contrast drought-driven N loss and the self-sustaining groundwater N accumulation mechanism.

## Foliar fertilization on reducing nitrate leaching and nitrous oxide emissions in potato field

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### Abstract

Nitrogen (N) fertilizer has long been used in agriculture to improve crop yields but the surpluses in consequence cause environmental problems, for example nitrate leaching is a main cause of the water pollution and nitrous oxide (N2O) emission is responsible for climate change and ozone depleting. As a target-oriented strategy, foliar fertilization which applies nutrient liquid directly to leaves was chosen and expected to reduce N losses. The experiment was conducted in a 5-ha potato filed located in central Jutland of Denmark, in which nitrate leaching was measured from suction cups and N2O was collected through manual chambers periodically during the growing season from May to late August 2023.

Compared with business-as-usual (BAU) application, the reduction in nitrate leaching and N2O emission was seen in foliar fertilization practice which is significant after rainfall. Soil properties and field topography are utilized for underlying explanation on a few unexpected data points. Overall, foliar application shows great potential for reducing N loss in modern agricultural fields.

## Impact of anaerobic digestion on water quality on livestock area

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### Abstract

Methane production by anaerobic digestion (AD) is quickly developing in farming areas in Europe. At the scale of a production system, the introduction of AD induces a variety of changes in agricultural practices, which may have positive or negative impacts on water pollution. The purpose of this work is to document these changes and to assess their impact on nitrate pollution and on nitrogen cycle at a small watershed scale in a livestock area. To do this, contrasting scenarios including several changes induced by AD were simulated using an agro- hydrological model Topography-based Nitrogen Transfert and Transformation (TNT2). The scenarios consisted, first, in constructing virtual farms (here, a pig farm and a dairy farm) whose fields would cover a subcatchment of the Kervidy-Naizin catchment (Brittany, France). Then, different options of changes were simulated, based on inquiries and observations in actual farms. The results are analyzed comparing, for scenarios of farms with or without AD, a variety of indicators on water and air pollution, nitrogen efficiency and farm productivity.

The results suggest that aiming at maintaining the agricultural productivity of the farm and producing methane on top may lead to increased risks of nitrogen losses. Conversely, good environmental performances and increased nitrogen efficiency could result of innovative management choices (Möller, 2015). Among these, methane production can allow pig farmers to convert valley bottoms in permanent grasslands, with co-benefits for the digester feeding and the water quality but with a reduction of feed autonomy of the farm if animal production remains similar (Prochnow et al., 2009)

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## Establishment of local coastal water boards to find bottom-up solutions for RBMP 2027

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### Abstract

The Danish EPA has set target for nitrogen loads for each coastal water to reach the goal of "good ecological status" and the reduction needed to be implemented in 2027. In this context four locally based pilot projects have been initiated to engage stakeholders to find local solutions for the RBMP. One of these new pilots are focusing on Hjarbæk estuary in Limfjorden, being one of the coastal water bodies in Denmark that needs the highest reductions in nitrogen loadings (ca. 65 %) (Kronvang et al., 2023). Because of the high reductions in nitrogen loadings needed it is necessary to reduce all sources and both nitrogen and phosphorus to reach the goal. The marine modeling of Hjarbæk estuary shows that the exchange rate between phosphorus (P) and nitrogen (N) is 1:22, meaning that reducing one ton of P corresponds to reducing 22 tons of N equivalents. Scenarios to reach the goal includes: i) marine mitigation measures ii) reductions in point source loadings; iii) N mitigation measures to be adopted at source; iv) use of transport mitigation measures from field to surface water v) use of different phosphorus mitigation strategies in the catchment (Limfjordsrådet og Viborg kommune, 2023).

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Nitrogen fertiliser input reduction threats soil fertility in a medium-term experiment in NW Italy.

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## Abstract

Europe's Farm to Fork strategy demands better fertiliser management to reduce nutrient losses by >50% and fertilisers use by >20% by 2030[1]. Thus, it is necessary to ensure that no deterioration in soil fertility occurs.

This study examines risks of decreasing soil fertility connected to the application of a 30% reduced nitrogen (N) dose to three maize-based forage systems. Field data were collected in the eight-year period 2012-2019 from the Tetto Frati Long-Term Experiment in NW Italy. Three cropping systems were compared (silage maize in monoculture, Ms; Italian ryegrass - silage maize double cropping, Mr; and silage maize-grassland 5-years rotation, Ml), each at two N levels (250 and 170 kg ha$^{-1}$), using bovine slurry S, farmyard manure F or urea U. Yield, nutrient uptake, soil mineral and total N contents (SMN, STN), soil organic carbon and soil Olsen P were monitored. Accumulated soil surface N balances over time showed a negative trend (except for Mr250S), with an annual average N deficit of 15-119 kg N ha$^{-1}$. During winter, the SMN variation (proxy of N mineralisation minus leaching losses and immobilization) was positive, with higher values in grassed systems, in the range 13-34 kg ha$^{-1}$ yr$^{-1}$.

The data reveals that winter N mineralization exceeded losses as leaching or immobilization at all fertilisation types and levels, and net mineralization occurred. Negative soil surface balances and STN variations confirmed that crops utilized nutrient pools not supplied by fertilisers, thus eroding soil resources, and depletion was 38% larger in systems at reduced fertiliser supply.

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## Potential for nitrogen recovery in industrial biowaste composting

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### Abstract

Household biowaste is an important composting resource in Germany, averaging 128 kg per inhabitant annually (BMUV, 2020) and containing more than 10 Mio tons of nitrogen (N) if whole Germany is considered. During composting, the biowaste N is transformed with ammonification being the most crucial process in terms of N losses. Laboratory experiments indicate N losses via ammonia in a wide range with a maximum of 70% of the initial N (Körner, 2008). A real-scale study was conducted in 100 m³ composting boxes with normal and enhanced aeration modes (Bharadwaj, 2023). The biowaste total and ammonia N as well as the N compounds in the compost after 9 days of rotting were measured. Results showed that N loss in the normal aerated mode was insignificant, and in the enhanced mode around 10% of initial N, primarily in the form of ammonia.

The overall treatment of biowaste in the selected industrial composting facility is more complex. It includes anaerobic digestion as pre-treatment involving aeration and dewatering of digestate, as well as post-composting. Mass and N balances were conducted using a combination of company, literature, modeled and measured data. The most significant losses were encountered during the aeration of digestate.

In the company, ammonia losses from intensive rotting are mostly trapped and disposed to wastewater treatment. Additionally, some of the ammonia is transformed in biofilters. The most N escapes to the environment during digestate aeration. With capturing technologies these N losses could be recovered to produce liquid fertilizers.

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## Reducing nitrogen losses using strategically timed applications in the Australian Cotton Industry.

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### Abstract

Fertilizer application strategies in the Australian cotton industry are varied and can includ: a single, split, fertigation, or foliar liquid programs. The most common strategy is to start with a single application pre-sowing (with urea or anhydrous ammonia); however, all involve several additional in-crop applications as a "peace of mind" strategy to ensure every chance is given to reach optimum yield. Five field experiments were undertaken from 2013 to 2016 to investigate N timing application strategies. Yield, N uptake, and internal nitrogen use efficiency (iNUE - kg lint/ kg N Uptake per ha) were captured from the experiments. The results showed that there was no yield penalty across the various N application strategies over the three seasons, however, N uptake was highest for split applications (>300 kg N/ha) and lowest for late single applications (111 kg N/ha). The iNUE was highest (19) for the late single application in February and lowest (9) for split applications, where the second application was higher (120 kg N/ha) than the first application (100 kg N/ha). Varying the timing of N (single or split) did not impact yield and suggests that adequate mineralization was occurring. These factors, combined with an adequate single application (e.g. 200 kg N/ha in September), suggest that no additional N would be required. Later applications of N are not critical when levels are adequate and mineralization is occurring, highlighting the need to sample for N with plant-based techniques to avoid over-fertilization and reduce losses.

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# Actual trends in nitrate leaching potential from agriculture in Germany

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## Abstract

According to the European Nitrates Directive (91/676/EEC), regionally high nitrate pollution of ground- and surface water from diffusive sources from agriculture needs to be reduced. In the frame of the demonstration project "Multiparametric monitoring of nitrate loads in agriculture" (MoNi), a set of indicators is applied at field and farm scales. The aim is to assess their suitability to monitor nitrate leaching potential and to determine whether the measures embedded in the recently amended fertilisation legislation in Germany are effective to reduce nitrogen (N) leaching from agricultural fields. Data for field N balances, farm N balances, and soil mineral nitrogen contents (SMN) have been collected since 2017 on 576 fields in five test regions. On a quarter of the fields, additionally mineral nitrogen concentrations in the subsoil (120-300 cm, subMN) are measured yearly. The monitoring has increased since then to 1116 fields from 96 farms being monitored in 12 test regions across Germany. The participating farms are involved in arable farming, animal husbandry and vegetable growing. We found that for individual fields, the indicators observed at soil surface (nitrogen balances), in the topsoil (SMN) and in the subsoil (subMN) often show inconsistent nitrate leaching potentials. Therefore, the simultaneous observation of several indicators is reasonable. We found that N surplusses have declined and nitrogen use efficiency has increased significantly since 2017, mainly by reduced N supply. However, this trend is not yet evident in SMN in autumn, which is strongly influenced by post-harvest management, location and weather conditions, or in subMN.

## Acknowledgements:

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## Effective catch crops with minor residual effect on yield and nitrate leaching when discontinued

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### Abstract

Catch crops (CCs) are common tools to uptake soil nitrogen (N) and reduce nitrate leaching after the main crop. The N retained by the CCs may increase the N release compared to bare soil both in a cropping system with continuous CCs and if the use of CCs is discontinued. The residual N may affect the main crops and nitrate leaching over the years.

We evaluated the effects of continuous CCs in spring barley on yield and nitrate leaching under four fertilizer levels (0-150% of recommended N) at Foulum (9.9 % clay) and Flakkebjerg (10.5 % clay) in Denmark. After four years of CC growing, plots were left bare to assess the residual effects on grain yield and N uptake and nitrate leaching. Spring barley followed by bare soil was used as a reference.

Growing CCs generally had a positive effect on grain yield and grain N of spring barley over the four years when compared with spring barley with bare soil. In the year after the CC discontinuation a positive residual effect on grain yield and especially grain N uptake in spring barley was mainly seen at Foulum. Over the four years with continuous CC nitrate leaching decreased in the range of 24-89%. After discontinuation of CC, nitrate leaching increased at Foulum at the highest N level while minor differences were found at Flakkebjerg.

The experiments showed that CCs have a high potential for reducing nitrate leaching while the residual effect of CCs was mainly seen for N uptake.

## Can novel slurry management techniques maintain nitrogen-related grassland soil functions?

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### Abstract

Climate change is inducing loss of soil organic carbon (SOC) and total nitrogen (N) from pre-alpine grasslands, thereby endangering soil functions. At the same time, organic fertilizer management has been constantly changing, from predominantly farmyard manure to broadcast spreading of liquid slurry and to recent upper limits of organic N fertilization and obligatory application at the soil surface. Still, the impacts of these refined fertilizer application techniques on gaseous N losses, the total N balance, as well as productivity and fodder quality are little understood. Therefore, we conducted a series of grassland management experiments in Southern Germany using $^{15}$N-labelled cattle slurry to trace fertilizer N fates in the plant-soil system and to set up total N balances. We tested a range of management techniques and intensities, with further treatments including different soils and experimental climate change simulation.

We frequently observed soil N mining due to large plant N exports and slurry N losses, accompanied by SOC losses as well. Soil N mining increased with management intensity and climate warming. Slurry acidification reduced N losses and promoted plant N uptake. Slurry injection efficiently reduced N losses on low pH soils derived from silicate bedrock, but not on high pH soils derived from carbonate bedrock. The use of slurry separated into liquid and solid fractions increased productivity and reduced total N losses, but strongly increased N2O emissions. In sum, we provide a synthesis of the impacts of alternative slurry application techniques on fertilizer N balances of high relevance for agricultural practice.

## Delays in nitrogen losses to streams following implementation of measures.

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### Abstract

Reducing nitrogen (N) leaching from grown fields will not always have an instant effect on the resulting N load in streams to the end receiver – the coastal waters. In Danish streams a substantial part of the leached NO3 is reduced in anoxic groundwaters before entering the streams. Furthermore, in some catchments a legacy will lead to a response time of several years (even decades). This legacy - among others- can be related to the relative amount of oxidized groundwater in the hydrological cycle.

Longer-term development in N-concentrations in the rootzone can be related to the N-concentrations in streams by establishing a simple lag-time model. Such a model can assist in quantifying N-delays not yet observed in streams and also forecast the expected delay time for the full effect of further planned measures in agriculture for reducing NO3-leaching to be observed in streams. We will share examples of N-legacies for eight longer-term monitored streams delivering N-loading to two Danish estuaries.

Knowledge of N-legacies are important to include when evaluating the N-response of measures adopted under the River Basin Management Plan of the EU WFD. Furthermore, such knowledge can be used when choosing between measures focused on either reducing the N-leaching from the fields or focused on transport measures that helps to increase the N-retention in catchments. The latter leading to quick response on the N-loading to coastal waters.

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## Climate change impact on hydrological and nitrogen cycling in an intensive agricultural watersheds in Brittany, western France

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### Abstract

The objective of our study is to assess the climate change impact on hydrological and nitrogen cycling in intensive agricultural watersheds in Brittany, western France. The Quillimadec (89 $km^2$) and Semnon (267 $km^2$) watersheds were selected in this region for their contrasting pedoclimatic conditions and agricultural production. First, we calibrated and validated the agro-hydrological, TNT2 model (Beaujouan et al., 2002), for the water discharge, nitrate concentration and loads at the outlet of both watersheds. Then, we simulated twelve combinations of global climate models and regional climate models under the RCP8.5 emission scenario in each watershed from 2023 to 2053. The climate data from this selection are already biased and this selection captures the divergence in climate data. In addition, we considered two agricultural scenarios: the adoption of agroecological practices and the continuation of the current agricultural intensification. The increasing atmospheric CO2 levels is also considered in our simulations.

The results of this study are currently being processed, and we will present our findings at congress.

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How does slurry application technique affect gaseous nitrogen losses?

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## Abstract

The impact of gaseous nitrogen (N) losses from denitrification is economically relevant to crop yield and contributes to climate change. The amount of denitrification losses is extremely variable as it depends on climatic factors, management and soil properties. The role of gaseous losses from denitrification has hardly been researched in the areas of fertilisation, soil cultivation and crop rotation. One reason for this is that quantifying $N_2$ emissions from fertilisation is challenging due to the high atmospheric background concentration. Within the joint project MinDen, a field experiment has been set up in Braunschweig, Germany. The aim is to assess the impact of mineral or organic fertilisation and different application techniques of organic fertiliser on gaseous nitrogen losses from denitrification and on nitrogen use efficiency. Nitrogen losses are quantified using $^{15}N$ labelled fertiliser and calculating the $^{15}N$ balance. In combination with measuring ammonia losses after fertilisation, total N loss through denitrification can be estimated. Additionally, the static chamber method and the $^{15}N$ gas flux method are applied to determine the temporal course of nitrous oxide ($N_2O$) and $N_2$ emissions and to validate the $^{15}N$ balance loss. Initial findings show that in a maize crop the $N_2O$ emissions were low, as anticipated due to the sandy soil. We did not find any differences in yield. However, preliminary results suggest differences in the $^{15}N$ balance while the uncertainty calculation of the $^{15}N$ balance provides important information about the accuracy of the balance.

## Acknowledgements

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# National estimations of annual nitrogen losses by runoff in Norway – Chances and limitations

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## Abstract

Excessive nitrogen (N) input to waterbodies disturbs aquatic ecosystems worldwide and so also, among others in Norway, the Oslofjord. Knowledge about the main N sources is important to provide politicians advice for efficient reduction of N input. To quantify the contribution by agriculture, an empirical model was developed with the purpose to be applicable to the total agricultural area of Norway. Model development was based on 30-years monitoring of water quantity and quality of six catchments across Norway. These catchments are part of the National Agricultural Environmental Monitoring Programme (JOVA; jovadata.nibio.no) and represent typical agricultural production for Norway. A multiple linear regression combines eight variables accounting for annual water runoff, nitrogen balance, temperature during main growing season, dominating soil texture, and subsidised environmental measures to estimate annual N loss by runoff from agricultural area at first order catchment scale. The model was evaluated by independent data of other JOVA catchments and 30-years monitoring data from the Swedish National Catchment Monitoring Programme. The applicability of the model to the total agricultural area of Norway was estimated following Meyer et al. (2024). Application of the model to independent monitoring data showed good agreement for both, the JOVA catchment, and the Swedish catchments. However, area of applicability of the model is limited to around 50% of Norwegian's agricultural area when considering all eight variables. The most problematic areas are those with more than 1500 mm annual water runoff as no monitoring catchment covers such high runoff.

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## Riparian zones as $N_2O$ and $CH_4$ hotspots: Incidence of extreme weather events and vegetation

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### Abstract

Through a field research, we aimed to contribute to the understanding of Mediterranean riparian ecosystems, reactive in terms of carbon and nitrogen loss and retention. We assessed $N_2O$ and $CH_4$ patterns and major influential drivers. We hypothesized that emissions would vary along a riparian transect, from the water stream to inland areas, with different soil properties, e.g., linked to water content, nutrient availability and associated microbial communities as well as spatial variations depending on vegetation by studying two zones with different plant species dominance. We also expected to observe a temporal pattern with higher emissions during spring and autumn, months with higher precipitation in the Mediterranean climate, and capture how extreme weather events can affect these emissions. For two consecutive years, $N_2O$ and $CH_4$ fluxes were measured monthly using the closed chamber technique (Sanz-Cobena et al., 2014). For each replicate, we collected soil samples in the 0-5 cm layer with the same frequency as the gas samples to measure mineral N, soil organic carbon (SOC) and water moisture. The abundance of nitrifying and denitrifying genes was estimated by quantitative polymerase chain reaction (qPCR) analysis as detailed in Bozal-Leorri et al., (2023). Our results showed notable differences in the emissions of the two GHGs in relation to the distance from the river and therefore the water content of the soil. A significant influence of flooding associated with heavy rainfall was observed on both $N_2O$ and $CH_4$ fluxes. Overall, the studied systems are landscape GHG emission hotspots when compared to nearby croplands.

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Authors acknowledged to "AgroGreen-SUDOE" project (SOE4/P5/E1059).

# Seasonal dynamics of cover crop N effect for sugar beet caused by cover crop species and environment

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## Abstract

Cover crops (CC) are able to scavenge the soil from mineral N (SMN) in autumn, thereby reducing the risk of leaching. Further, they are expected to increase the N supply to subsequent main crops. However, data on N supply from CCs grown before sugar beet (SB) are scarce.

In 2018/19 and 2019/20, field trials were conducted on two Luvisol sites in Germany, comprising autumn sown CCs followed by fertilized (60-150 kg N $ha^{-1}$ uniform across all CC per site/year) SB next spring. The N effect of CC (Neff) was calculated as the difference between SB N uptake after CC and bare fallow for the periods sowing to mid-summer and mid-summer to harvest in autumn.

Across all site/years, SMN at sowing was highest after bare fallow and lowest after winter rye and oil radish, whereas after saia oat and spring vetch SMN was intermediate. In the period sowing-summer, at three site/years, Neff was 0-50 kg N $ha^{-1}$ after all CC except rye, where it was -20 to -50 N $ha^{-1}$. In contrast, at one site/year, Neff after rye was positive. In the period summer-harvest, Neff was negative with up to -100 kg N $ha^{-1}$, except after vetch at one site/year revealing a positive value. For both periods, SMN was positively correlated with Neff at three site/years, whereas the relationship between CC properties (biomass, N content, CN ratio) and Neff was variable. In a comprehensive multiple regression analysis, soil and weather parameters could not unravel drivers of site/year specific differences.

# Autumn measured soil inorganic nitrogen as a prediction of nitrate leaching and load to tile drains

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## Abstract

While Denmark has implemented several action plans to improve water quality, the agricultural losses of nitrogen are still high to fulfil the aims in the water framework directive. Therefore, additional mitigation measures are needed along with effective methods to evaluate their effects. Inorganic nitrogen concentration in the upper 1 m of the soil measured in autumn, is an indicator of the potential for leaching of inorganic nitrogen from the root zone during the following period. The challenge is to determine the optimal time for sampling, that both includes, the highest amount of soil inorganic nitrogen and the lower concentrations by the up-take of catch crops or winter crop in autumn.

Additionally, soil samples must be taken before inorganic nitrogen in the soil is lost by percolation.

We will present pros and cons of the N-min method and explore relations between measures of N and nitrate leaching, nitrogen load, and flow weighted total nitrogen concentration in tile drains. We found a high correlation between N-min and the flow weighted total N concentration in four tile drains ($R^2$ = 0.99 for the runoff period October-Marts in 2015 and $R^2$ =0.98 in 2016). High N-min in autumn and subsequent high total N losses to tile drains were found on fields with peas and deep litter applications.

A new four-year project, NITAGRO, aims to model the link between N-min measured in autumn and nitrate leaching. And evaluate the connivance of including plant biomass estimation inferred from satellite images to predict N-min or nitrate leaching.

## Dutch potato yields can be maintained with lower N inputs: great promise for lowering N surplus

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### Abstract

In arable farming systems in Northwest Europe high yields are obtained, but they are coupled with high nitrogen (N) application rates and losses. Lowering application rates and thereby increasing resource use efficiency and reducing emissions to the environment is essential to move towards a more sustainable agriculture. In this study, we aimed to quantify and explain variability in nitrogen use, surplus and efficiency for ware potato production in the Netherlands. Over two growing seasons, we closely monitored 96 ware potato fields and assessed variability in yield and management. Average total N input was 448 kg N/ha on clay soils (range: 271-978 kg N/ha) and 319 kg N/ha on sandy soils (range: 155-525 kg N/ha). Nitrogen use efficiency was on average 44% on clay soils and 59% on sandy soils. Thresholds for desired N surplus were achieved in only 4% of the fields on clay soils and 19% of the fields on sandy soils. Regression analysis showed that N input was the most significant contributor for explaining variability in N surplus, while it hardly affected yield. In addition, there was a small effect of year and irrigation on N surplus. Hence, lowering N input rates is the most effective way to reduce N surplus, while yields can be largely maintained. Relatively low N use efficiency suggests that there is also an economic loss for farmers. However, a simple cost benefit analysis showed that risk aversion may partly explain farmers' rationale with regards to N application rates well above crop demand.

## Policy intervention to manage synthetic N fertilizer use in India

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### Abstract

India has experienced strong economic growth in recent years. Agriculture being a major economic activity in the country, India uses large quantities of N-fertilizer consuming a total of 20.4 million tons in 2020-21. Although fertilizer use has increased severalfold, the nitrogen use efficiency (NUE) has been gradually decreasing in India, from 55 to 35% between 1960 and 2010 (Sapkota et al., 2023), leading to increasing waste of reactive-N ($N_r$) resources. $N_r$ pollution from synthetic fertilizer has become a major environmental issue in India across all scales. The agriculture sector (including livestock) of India contributed to 77% of overall emissions of $N_2O$, and 87% of $NH_3$ emission. Of this, fertilizer-N applications alone contributed 48% to overall country emission of $NH_3$. Agricultural policies, including legislation, acts, amendments and regulations, including crucially those related to fertilizer subsidies, influences how synthetic N-fertilizer is used. Policies and extended subsidies have significant link with the use of nitrogen fertilizer. A total of 15.36 billion USD was spent as subsidy for fertilizer use in 2020-2021 out of which 10.87 billion USD was spent in India for urea alone. Halving the N-use by 2030 would result into savings of resources and reducing the environmental impact of $N_r$. Hence, it is important to establish a baseline understanding of the national and regional policies that can influence synthetic N-fertilizer imports, exports, production and use to control Nr emission in agriculture in India. Government of India is aware of its responsibilities by continued introduction of new N-related policies over the years.

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# Protecting nature areas by taking dedicated regional measures

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## Abstract

Nitrogen policy in the Netherlands has a long history. Since the 70's of the last century, various measures have been implemented in an attempt to reduce emissions of different nitrogen compounds. A few examples of a wide range of measures implemented since then are the introduction of catalytic converters removing nitrogen oxides from fossil fuel burning, shallow injection of manure into the soil reducing ammonia emissions to air and lowering of the manure application rates. In 2019, the European High Court judged that the Dutch nitrogen policy with respect to nitrogen deposition onto protected nature areas was not in accordance with the European Habitats Directive. All infrastructural developments came to a halt: building houses, roads, etc. stopped. With a new Minister on Nitrogen in place since 2021, the focus became a drastic reduction of nitrogen emissions to get the nitrogen deposition below the nitrogen critical loads for 74% of the protected (Natura 2000) nature areas, which is laid down in a nitrogen law. This requires a drastic change in activities in and around these nature areas, mainly (but not exclusively) focusing on the agricultural sector.

This because the contribution to the total nitrogen deposition of this sector is on average 50% in the Netherlands. To help policymakers take measures as efficiently as possible, RIVM has developed a tool that maps the origin of the nitrogen deposition in each nature area. In this way, the government, provinces and other stakeholders can take dedicated regional measures to reduce the nitrogen emissions.

# NITROGEN LOSS MITIGATION STRATEGIES UNDER RICE-MAIZE- MUNG BEAN CROPPING SYSTEM IN NEPAL

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## Abstract

Rice–maize systems are rapidly expanding in South Asia due to higher yield and profit potential; however, the higher yield is mostly associated with high application of nitrogenous fertilizer exacerbating N loss and GHG emission. A field experiment was conducted in tropical condition of Nepal in 2022/23 to identify better nitrogen management options for higher crop productivity, N use efficiency and N loss mitigation under a rice-maize-mung bean cropping system. The recommended dose was 120:40:40, 120:60:40 and 20:40:20 kg NPK per hectare for rice, maize and mung bean, respectively. The experiment was conducted in RCBD with eight treatments: $N_0$, prilled urea (PU) @ RDN, PU @ RDN+25%, PU @ RDN-25%, cattle manure @ RDN, poultry manure @ RDN, urea briquette deep placement @ RDN-30%, and SSNM @ RDN, replicated four times. Results has demonstrated that cattle manure performed best in terms of growth, rice equivalent yield, agronomic efficiency and ammonia volatilization mitigation in rice and maize; while poultry manure performed best in terms of growth and biomass yield in mung bean. Farmers are recommended to reduce the dose of PU by 25% in rice and maize crops and reduce ammonia volatilization without compromising yield, if they incorporate mung bean as green manure in rice-maize cropping. Policy makers are suggested to promote organic farming through the application of organic manures and green manuring, while significantly reducing the problem of N-fertilizer shortage and N losses in Nepal.

Key words: Ammonia volatilization, Agronomic efficiency, Cattle manure, Prilled urea, Urea briquette deep placement

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From livestock to crop production: a coherent agricultural ammonia inventory for Europe

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## Abstract

Ammonia (NH3) emissions from European agriculture are creating negative environmental impacts such as terrestrial eutrophication, acidification, and air pollution. Changes to agricultural production are required to ameliorate these issues (Schulte-Uebbing and de Vries, 2021). To accommodate this, we need to distinguish emissions by crop and livestock commodity. Here, we constructed a coherent crop-livestock ammonia inventory identifying emissions from 17 crops, 2 grasses and 6 livestocks over Europe at a spatial resolution of 5 arc minutes for the year 2015. Our results show that 3.5Tg NH3 were emitted from the European agricultural system, where 76% and 24% of emissions were attributed to animal and crop commodities, respectively. Among livestock emissions, feed production, manure management, and manure deposited plus application accounted for 12%, 53% and 35%, respectively. The top six emitting commodities, dairy cattle, other cattle, pigs, poultry, wheat, and barley, contributed to 90% of emissions. NH3 emissions by per unit of commodities descend as ruminant meat commodities, milk and monogastric commodities, fruit and vegetables, cereals and protein crops. Emission hotspots occur in Benelux, Denmark, Germany, Czechia and the UK, where dairy cattle, other cattle and pigs represent dominant emitting commodities. Furthermore, the uncertainty analysis confirmed the robustness of results at NUTS2 level. Our findings can help assess how to alleviate nutrient emissions and promote a sustainable, low emitting European food system.

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# Effect of DMPP-coated urea on urine patch $N_2O$ emissions

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## Abstract

Urine patches represent major inputs of nitrogen, equivalent to up to 1000 kg N ha$^{-1}$. In intensively grazed dairy systems these can cover over 10% of the paddock area annually and are major point sources of $N_2O$. While substantial research has been conducted on the efficacy of spraying nitrification inhibitors such as DMPP or DCD on patches to slow the nitrification of $NH_4^+$ to $NO_3^-$, limited research has been conducted examining the effectiveness of inhibitor coated urea fertilisers on losses.

The trial was conducted on a commercial dairy farm in north-eastern NSW, Australia. Treatment application mimicked the typical summer dairy practice in the region where the urea fertilisers were applied prior to every second grazing. Urine was applied at 750 kg N ha$^{-1}$, with urea coated with and without the inhibitor DMPP (ENTEC™) added at 56 kg N ha$^{-1}$. Automated chambers monitored $N_2O$ for 60 days following application from urine only, standard urea, and urea plus DMPP plots.

The combination of fertiliser urea on top of the urine patch increased losses by over 50%. However, total $N_2O$-N losses over the experiment totalled less than 4 kg N ha$^{-1}$, extremely low considering the 750 kg N applied and once again emphasizing that major losses are mainly limited to extreme rainfall events. The combination of DMPP and urine reduced $N_2O$ emissions by 24%, with the majority of this reduction occurring within the first week after urine application. There was no effect of inhibitor or urine on pasture yield over the duration of the short trial.

## Potential for DMPP to increase pasture yields and reduce N losses following repeated application in Subtropical Australian dairy systems

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### Abstract

Up to 40% of fertiliser N can be lost in high-input subtropical dairy pastures, and while some enhanced efficiency fertilisers such as DMPP have been tested, previous findings have been mixed (Dougherty 2016, Rowlings 2016). A longitudinal experiment was conducted on a ryegrass/kikuyu pasture on a heavy clay in eastern Australia to determine if DMPP is effective in increasing yields and agronomic efficiency of N fertiliser.

Treatments were applied to the same grazed plots over three years to ensure any long-term effects associated with increased fertiliser immobilisation from the inhibitor (as seen in Friedl et al., 2017). DMPP was compared at a 25% reduction (1.5 kg N $ha^{-1}$ $day^{-1}$) against standard farmer practice (2 kg N $ha^{-1}$ $day^{-1}$) urea rate.

DMPP had the greatest effectiveness at the lower application rate, with limited benefit observed at the higher rates where the retention of N in the soil-plant system has less impact on yield. An average increase in ryegrass yields of 15% was observed in the first two years, and over 70% in year 3 compared to the equivalent N rate as urea only. Even at the higher price premium for the DMPP fertiliser, the increase in harvest return from additional pasture growth far outweighed the additional cost. However, due to plateauing pasture growth to N inputs as other factors such as moisture, temperature, other nutrients etc. become growth limiting factors, the additional expense of the product meant profit and marginal profit declined rapidly once application rate surpassed the optimal.

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## Nitrogen Budget & Footprint for Eswatini Kingdom: A Multi-decadal Country Specific Perspective.

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### Abstract

We present the first multidecadal country-specific N footprint for the Kingdom of Eswatini from 1961 to 2021. Similar to most developing countries, the fate of the N footprint for Eswatini is a double-faced challenge of low N input and higher N losses. Meticulously, the paper estimated the N use efficiency (NUE), virtual N factors (VNFs), and N footprint for the agro-food systems of fertilized farms. We used N-calculator model to estimate the agro-food products for 61 years in a fertilized scenario. The following vegetal and animal products were considered: maize, rice, starchy roots, fruit, chicken, eggs, cattle and small ruminants (goats, pigs). The VNF factors for Eswatini were similar to those of Tanzania[1], Malawi[2] and Rwanda[3]. A comparison between 1961–1971 and 2011–2021 demonstrated several variations in the agriculture system, such as an increase in the production of most crops except vegetables (-17.60%) and sugar beet (-1.85%). Similarly, production of most livestock increased except for sheep (-8.34%). The grand total protein supply decreased by -7.57%. The Eswatini Kingdom had an annual average N footprint of 14.6 kg N $ha^{-1}$ $yr^{-1}$ from 1961 to 2021, whereby 12.5 Kg N/$cap^{-1}$/$yr^{-1}$ was the virtual N footprint and 2.07 kg N/$cap^{-1}$/$yr^{-1}$ was the consumption footprint. We recommend an increase in N input and proper farming practices which can improve N use efficiency and productivity. Further studies are therefore required to assess how international trade influences the perturbation of the nitrogen budget and link the footprint to the associated environmental effects.

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# Stable nitrogen isotopes in agriculture

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## Abstract

A useful tool for investigating nitrogen cycling is by measuring isotopic ratios. Different processes discriminate against heavy molecules such as the naturally abundant $^{15}N$ and alter the ratio of both isotopes, described as a **δ** value in ‰. During reactions such as denitrification or biological nitrogen fixation the light isotopes react at a higher rate, while the heavier molecules tend to remain in the residual material. Hence, the residual substrate will be enriched in $^{15}N$ compared to the resulting product (Denk et al., 2017; Hobbie & Ouimette, 2009). The ratios can furthermore be visualized in form of a map as so-called isoscapes. The project I'm currently working on is to measure isotopic ratios of soil, grain, and fertilizer samples from an agricultural test field west of Copenhagen. The aim is to examine the differences between fertilizer treatments, investigate fractionation processes between fertilizer, soil and grain and furthermore identify hotspots with particularly high delta values (corresponding to a high amount of heavy nitrogen). As high delta values indicate nitrogen loss, it could give valuable insights to link those to fertilizer treatments.

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## Factors influencing nitrogen derived from soil organic matter mineralisation: results from a long-term experiment

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### Abstract

Mineralised nitrogen (N) from soil organic matter (SOM) represents a crucial source of N for both natural ecosystems and agroecosystems. Therefore, accurate estimation of the amount of N available to crops from SOM mineralisation is necessary to reduce the losses of N. This study aimed to quantify the influence of environmental and soil variables on N mineralised by SOM in an agroecosystem, based on the assumption that N uptake by non-fertilised crops serves as an indicator of N derived from SOM. The study analysed 29 years of crop, agrometeorological and soil data from three different maize cropping systems from a long-term experiment conducted in the NW region of Italy. A Linear Mixed Model (LMM) was developed for the purpose of the study. The average of SOM mineralisation predicted by the model was 96 kg $ha^{-1}$ $yr^{-1}$ with a root mean square error of 21 kg $ha^{-1}yr^{-1}$. The fixed factors of LMM, which were soil organic carbon, carbon-to-nitrogen ratio and the sum of rainfall and irrigation, are responsible for 19% of the annual variations in mineralised N. Including the cropping systems and interannual variability as random factors, the explanatory power of the model increased to 52%. In a future climate scenario characterised by increased aridity, N mineralisation could therefore decrease, thus increasing the demand for fertilisers. This recalls the fundamental importance of adopting correct agricultural practices that can hamper the SOM decrease and restore the SOM stocks.

# AMMONIA EMISSIONS FROM A BROILER HOUSE WITH HEAT EXCHANGER

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## Abstract

We conducted continuous measurements of NH3 emissions in two identical broiler houses at a single site in the eastern region of Switzerland throughout an entire production cycle in February 2024, employing a case-control study design. One house utilized a heat exchanger in conjunction with a supplemental gas-fueled heating system when needed (H-HE), while the other served as a reference with a conventional gas-fueled heating system alone (H-Ref).

Both houses started the production cycle with 8640 broilers (H-HE: 36 days; H-Ref: 35 days).

Concentrations of ammonia and carbon dioxide were measured at all air inlets and outlets utilizing X-node NH3 and CO2 sensors (Dräger Safety AG & Co. KGaA, Lübeck, Germany). Ventilation rates were continuously monitored at each outlet point utilizing measuring fans adapted to the dimensions of the air ducts (AQC, Stienen BE, Nederweert, The Netherlands). Indoor temperature and moisture content data were obtained from the operational systems of the houses. Ambient meteorological conditions were recorded by a weather station (Lufft WS700-UMB Smart Weather Sensor, G. Lufft Mess- und Regeltechnik GmbH, Fellbach, Germany) situated near the buildings.

Preliminary analysis of the measurements showed that NH3 fluxes remained slightly above 0 mg s-1 during the initial half of the production cycle, but notably increased from day 24 onwards. NH3 emissions from H-HE were approximately 50% lower than those from H-Ref.

## No tillage increased $NH_3$ volatilization losses in rainfed barley: results from the Integrated Horizontal Flux method (IHF)

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### Abstract

Conservation agriculture practices such as no tillage are of major relevance when seeking to mitigate the loss of soil organic matter through erosion and destruction of soil aggregates. However, the effect of tillage intensity on ammonia ($NH_3$) volatilization losses has been barely evaluated in field conditions, particularly using micrometeorological methods such as the integrated horizontal flux (IHF), which require large surfaces. We conducted a three-replicated field experiment in a rainfed barley (Hordeum vulgare L.) crop in central Spain (Madrid region), in which $NH_3$ volatilization losses from non-tilled plots were compared with those from conventionally tilled using the IHF method (Guardia et al., 2024). Barley was fertilized at seeding (40 kg N $ha^{-1}$) and at top dressing (120 kg N $ha^{-1}$), using urea at both times. The $NH_3$ volatilization factor was higher after basal (average 18%) than after dressing fertilization (average 7%). Considering both periods, cumulative $NH_3$ emissions were significantly higher in no tillage (19.9 kg N $ha^{-1}$) than in conventional tillage (12.2 kg N $ha^{-1}$). The effect of the number of IHF replicates on the results was also addressed. The statistical analysis revealed that the use of two replicates would only lead to significant differences between tillage intensities in 22% of the possible combinations, while the implementation of non-replicated IHF experiments for $NH_3$ should be avoided. Our results confirmed that the risk of increasing $NH_3$ volatilization losses when adopting no tillage, so we encourage the use of well-known improved N management practices to prevent these negative side-effects.

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# Uncertainty in estimating N losses due to Incomplete Data, Interpolation, and Water Flux Estimation

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## Abstract

Optimizing farm management practices for reducing nitrogen (N) losses, including leaching and gaseous emissions is hindered by the lack of technologies for real-time in-situ measurements of N concentrations in the soil or soil solution.

As the soil solution is a very dynamic pool, responding to any changes in the nutrient supply/demand system, collection and analysis of it is vital for studying nutrient cycling. Traditionally, soil solutions are obtained via suction cups or soil coring, which is time consuming and costly, limiting how many samples can be taken, leading to uncertainty regarding temporal and spatial variability (Weihermüller et al., 2007), and the need for interpolation between measurements. Another problem, when estimating N leaching losses is the unknown water flux, which is generally obtained from water balance models. Depending on the complexity of such models, estimated water fluxes can be quite different, which has a flow-on effect onto the calculated N losses.

This presentation will discuss various approaches for dealing with such incomplete data, different interpolation methods, and water balance models and their associated uncertainties. Finally, a real-time monitoring system, currently under development will be presented, which will provide real-time soil data of N fluxes, moisture, pH and dissolved oxygen. This will enable better estimation of N losses (gaseous and leaching) improve our understanding of hot moments in N cycling after fertilization and rainfall/irrigation, critical for the development of develop smart fertilization practices. Continuous soil solution data of N and environmental drivers will also provide valuable data for use in process-orientated models.

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How does erosion status affect soil N dynamics and gaseous N losses?

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## Abstract

Soil erosion is one of the main causes of nutrient losses in agriculture and has a major impact on nitrogen (N) distribution in soils. Nevertheless, up to now little is known about erosion-induced changes on N transformation processes and gaseous N losses.

To quantify the effect of soil erosion status on N dynamics and gaseous N losses, a short-term $^{15}$N-tracer experiment was conducted under controlled conditions. Three erosion states were simulated by mixing different amounts of topsoil with subsoil material from a Nudiargic Luvisol. The soil was fertilized with $NH_4NO_3$, containing either $^{15}$N-labelled $NO_3^-$ or $NH_4^+$ to reach a $^{15}$N abundance of 50 atom% in soil. To determine the plant impact, half of the pots were planted with maize (Zea mays) seedlings. Nitrous oxide ($N_2O$) fluxes were measured automatically by gas chromatography. Dinitrogen ($N_2$) fluxes were quantified using the modified $^{15}$N gas flux method with $N_2$-depleted atmosphere and analyzed by isotope ratio mass spectrometry. To follow the different N transformation pathways, shoots, roots and soil mineral N were sampled. Gross N transformations were estimated by the Ntrace model. Nitrogen transformation were dominated by nitrification, while mineralization and immobilization were less important. Due to the short incubation time, most of the $^{15}$N labelled fertilizer was recovered in the soil N pool (up to 104%) without significant differences between the three erosion states. In contrast, gaseous $N_2O$ losses differed between the erosion states, with highest $N_2O$ fluxes for the non-eroded, weakly eroded and strong eroded topsoil, respectively, while the overall $N_2$ losses were rather low.

## Responses of wheat to reduced rainfall, nitrogen fertilization and pre-crops in Switzerland

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### Abstract

Projected rainfall decline due to climate change and the environmental protection demands for less nitrogen (N) fertilizer inputs pose potential threats to wheat (Triticum aestivum L.) yields. This study investigates the impact of these factors on wheat production in a warm-summer humid continental climate in Switzerland. The field experiment, conducted over three seasons, employed rainfed and rainout shelter treatments, reducing up to 40% of rainfall during grain filling. This was overlaid with two N treatments, four winter wheat genotypes, and three pre-crops. Soil mineral N (Nmin) was measured at tillering onset. The reduced rainfall during grain filling did not affect wheat yield. Nitrogen fertilizer showed no impact on yield when initial soil Nmin exceeded 50 kg N $ha^{-1}$, nor after poor crop establishment due to a wet autumn. In a wet season with initial Nmin ≤ 50 kg N $ha^{-1}$, wheat responded positively to N fertilizer after a brassica pre-crop but less so after a legume or cereal crop. Short-term resilience of wheat production to reduced rainfall and N fertilizer inputs was observed in warm-summer humid continental climates. However, the study emphasizes the vulnerability of wheat to excessive rainfall during sowing, leading to poor crop establishment. Notably, an impact on wheat yields was observed only after three consecutive years without N fertilizer, indicating a potential for decreasing N supply over a few years.

## NO and $NO_2$ emissions from Dutch agricultural soils: pathways and measurement methods

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### Abstract

Nitrogen (N) fertilization in agricultural soils induces pedogenic N emissions, with airborne N damaging natural soils of ecosystems through deposition. Optimizing N fertilization; (right place, right rate, right time and right source) is therefore crucial to reduce N losses to the environment. While strategies to reduce N losses in the form of $NH_3$ and $N_2O$ emissions are well-documented, understandings in emissions of the air pollutants NO and $NO_2$ (hereafter referred to as NOx) from agricultural soils, controlling factors and potential mitigation options remain limited. $NO_x$ and $N_2O$ emissions, thought to share common pathways, are often measured together using a closed chamber technique. However, this technique, effective for capturing emissions of less reactive gases like $N_2O$, may not be suitable for capturing emissions of highly reactive gases like $NO_x$. In a PhD study, we therefore aim to assess 1) the appropriateness of different chamber types for measuring $NO_x$ emissions, 2) the influence of physical and chemical soil characteristics – such as temperature, moisture content and $NH_4^+$, $NO_2^-$ and $NO_3^-$ content - on $NO_x$ emissions and 3) the extent of $NO_x$ emissions from Dutch agricultural fields. Employing a range of different techniques, from literature study to laboratory- to field-scale experiments to test these questions, the overall aims of this PhD project are to design an accurate method for assessing $NO_x$ emissions, to derive emission factors for $NO_x$ from Dutch agricultural soils and to explore mitigation options. Our results should indicate effective measures to reduce $NO_x$ emissions from agroecosystems.

Nitrification inhibitors - a tool to reduce $N_2O$-N emissions in winter wheat?

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## Abstract

The use of nitrification inhibitors (NI) during N fertilization is controversially discussed as a climate protection measure. The effectiveness of NI on soil-borne $N_2O$ emissions is highly dependent on soil and weather conditions (Li et al., 2018). As part of the joint research project NitriKlim (2023-2025), field trials are carried out throughout Germany. The effects of NI on greenhouse gas emissions and yield of winter wheat under local conditions are evaluated. Seven different fertilizer treatments are tested at Kiel site: urea applied in three N doses, urea with urease inhibitor and urea with urease inhibitor and NI in two N doses, ammonium sulphate nitrate (ASN) in two and three N doses and ASN with two different NI (DMPP, DCD) in two N doses. Total N fertilization amounted to 190 kg N $ha^{-1}$. N2O-N emissions were measured weekly throughout the year.

Cumulative N2O-N emissions from shortly after first N application until mid-November with uninhibited urea were 1.41 kg N $ha^{-1}$. The urease inhibitor reduced emissions by 5 %, addition of urease inhibitor and NI by 33 %. ASN applied in three applications emitted 0.78 kg N $ha^{-1}$. When applied in two doses, emissions were clearly higher (1.73 kg N $ha^{-1}$). The addition of DCD and DMPP led to a reduction of 24 % and 36 %, respectively, compared to ASN applied in two applications, but were still higher than with three applications. The use of NI proved to be an effective tool for reducing $N_2O$-N emissions from urea fertilizers. However, N2O-N release in ASN was reduced just as well by increasing the number of N applications with lower N amounts per N dose. The value of using NIs for $N_2O$-N reduction therefore depended on fertilizer form and management.

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## Measures to reduce nitrate and nitrous oxide losses from renovated grasslands

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## Abstract

Grassland renewal (ploughing and reseeding or temporary conversion to arable land) is a common practice used by farmers to combat declining yields in agricultural grasslands.

Renewal practices may lead to substantial nitrate ($NO3^-$) leaching and nitrous oxide (N2O) emissions. Most farmers in the Netherlands prefer renewal in autumn instead of spring because of better establishment of the sward and low weed infestation. Limited N uptake of reseeded grassland during autumn may, however, increase the risk of $NO3^-$ leaching and N2O emission. Potential options to mitigate these N losses are reductions in tillage intensity and N application rate, or the application of nitrification inhibitors. We assessed the effect of these measures as well as timing of renewal and the conversion of grassland to maize on NO3- leaching and N2O emissions. We conducted five field experiments at five locations in the Netherlands for one year each and measured crop yields, soil mineral N, $NO3^-$ concentration in groundwater and N2O emission. Averaged over all experiments, highest $NO3^-$ concentrations in groundwater were observed after autumn renewal (17.2 $NO3^{-}$-N mg $l^{-1}$) and autumn renewal combined with mitigation strategies (12.8-19.4 $NO3^-$-N mg $l^{-1}$), whereas renewal in spring (3.1 $NO3^-$-N mg $l^{-1}$) did not lead to an increase compared to the control (4.4 NO3-N mg $l^{-1}$). Grassland renewal increased N2O- emission by a factor 1.3-1.5 relative to the reference grassland. We conclude that autumn renewal leads to significant increases in the risk of $NO3^-$ leaching which cannot be mitigated by technical measures.

How wheat root development can determine denitrification rates in soils of glacial depressions in Eastern Denmark

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## Abstract

Nitrous oxide emissions from agricultural land largely contribute to the greenhouse gas budget worldwide. Denmark's glacial landscape has widespread depressions, typically flooded for 1-3 months per year. These depressions are considered as hotspots of N2O emissions, because of an increased nitrate availability and labile carbon due to fertilization and deposition of eroded soil material. Temporal waterlogging affects plant development in these depressions, thus their ability to deplete available nitrogen in soil. Moreover, living plants provide substrates as root exudates for denitrification. However, the effect of plants and roots on N2O emissions from glacial depressions is not yet so clear.

In this study, we aimed to elucidate how waterlogging influences nitrogen uptake from plants at different root growth stages, and to quantify how this would influence N2O emissions. We conducted a mesocosm experiment with depression soils subject to either saturated or freely-drained water conditions, and planted wheats at three different growth stages. The treatments of different wheat growth were tested against an unplanted control soil which also was exposed to either saturated or freely-drained water conditions. In order to differentiate how much N2O was produced from newly-added fertilizer, we applied a $^{15}N$ tracer. To follow the root development and quantify root traits, roots were imaged weekly.

We were able to demonstrate both root growth stage and soil water conditions were vital factors for observed denitrification rates. The growth stage of wheat had a clear influence on the fate of mineral nitrogen thus the emissions of N2O from these soil systems.



WORK SHOP 2024 AARHUS

# $N_2O$-emission reduction after long term application of nitrification inhibitor DMPP

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## Abstract

Nitrification inhibitors (NI) can be an effective tool to decrease direct and indirect nitrous oxide ($N_2O$) emissions from nitrogen-fertilization (e.g. Ruser & Schulz 2015). Currently, there is little data regarding long-term effects on $N_2O$-emission and the corresponding impact on the microbial community with the NI 3,4-dimethylpyrazole phosphate (DMPP).

An incubation experiment was carried out using soil samples from a long-term field trial by the University of Hohenheim with different management histories: (a) continuously fertilized with ammonium sulphate nitrate (ASN), (b) continuously fertilized with Entec26® (ASN+DMPP), (c) ASN (2007-2016) followed by Entec26® (2017-2023), and (d) Entec26 (2007-2016) followed by ASN (2017-2023). Soil samples were incubated for 12 weeks in dynamic chambers at 15°C with four fertilization treatments: ASN, Entec26®, ASN+Nitrapyrin and no fertilization. $N_2O$-fluxes were determined continuously by gas chromatography. Soil mineral nitrogen concentrations were monitored. $^{15}N$-labeling of the nitrate pool enabled the determination of gross nitrification rates and the analysis of the $^{15}N$-$N_2O$ fraction originating from the labelled pool. Surface soil samples were taken for microbial analysis by qPCR and amplicon sequencing targeting total bacterial and archaeal communities, and specifically for ammonia oxidizers.

DMPP and Nitrapyrin significantly reduced $N_2O$-emissions in all NI treatments. Surprisingly, we observed significantly lower $N_2O$-emissions (~30 %) even in soil samples d) without DMPP application over 7 years after sole ASN application. These observations were linked to a decrease in soil bacterial amoA gene abundance in all treatments which had a DMPP application history. We hypothesize that (long-term) application of DMPP results in a sustained depression of ammonia-oxidizing bacteria and a lower $N_2O$-emission potential.

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## Denitrification product ratios - are there systematic differences between models and observations?

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### Abstract

A significant share of nitrogen, applied as fertilizer to improve agricultural crop production, is denitrified by soil microbes and consequently lost for crop growth. Biogeochemical models help in providing accurate predictions for nitrous oxide ($N_2O$) and dinitrogen ($N_2$) emissions, which are essential for optimizing agricultural practices and assessing denitrification rates. Recent studies suggest, $N_2$ emissions might be higher than expected, potentially underestimated by models. This study assesses systematic differences in modelled denitrification product ratios ($N_2O/(N_2O+N_2)$) ($RN_2O$) by DNDCv.CAN and observations. A lysimeter experiment with growing winter wheat with reported estimates for $N_2$ and $N_2O$ emissions by closed chamber (flushed with an artificial -$N_2$ reduced-gas mixture beforehand) is used to evaluate the DNDCv.CAN model's performance. The experiment included a control without fertilization (N0), four treatments with the transformation of cattle slurry $^{15}NH_4^+$ and soil $^{15}NO_3^-$ using a double labeling approach via different techniques: a trailing hose with (THCSA)/without (THCS) acidification, and open slot injection with (SICSNA)/without (SICS) nitrification inhibitor (3,4-dimethylpyrazole phosphate). The observed $RN_2O$ averaged 0.1, 0.08, 0.09, 0.13, and 0.15 in treatments N0, SICS, SICSNI, THCS, and THCSA, respectively, while the model predicted much higher $RN_2O$ (0.85 for N0, 0.88 for SICS, 0.9 for SICSNI, 0.97 for THCS and 0.97 for THCSA). DNDCv.CAN consistently overestimated $RN_2O$, with denitrification losses being underestimated due to the underestimation of $N_2$ fluxes, indicating the model inadequately represented total denitrification losses and the denitrification product rate. Additionally, the study will present the results of model adaptations for a more accurate description of observed denitrification products.

## Monitoring changes of $O_2$ and $N_2O$ concentrations in the rhizosphere of young maize plants by combining $O_2$ optodes and $N_2O$ microsensors

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### Abstract

$O_2$ deficiency is a main prerequisite for denitrification promoting $N_2O$ formation in soils. Plant root growth alters $O_2$ concentrations in the rhizosphere and can therefore affect $N_2O$ formation. Increased microbial activity in the rhizosphere of growing plants promotes microbial respiration, which together with root respiration contributes to high $O_2$ demand and consumption in the rhizosphere.

To understand the effect of root growth on $N_2O$ formation in the rhizosphere, we developed a novel rhizotron design allowing to monitor $O_2$ and $N_2O$ concentrations at high spatial and temporal resolution. Rhizotrons were filled with 2.2 kg of silty loam soil and maize (Zea mays L.) was grown for 3-6 weeks. The 'window side' of the rhizotrons was closed with a PET foil equipped with an $O_2$-sensitive optode, allowing monitoring of $O_2$ concentrations in the developing rhizosphere and surrounding soil at high spatial and temporal resolution. $N_2O$ concentrations in the soil profile were measured with $N_2O$ microsensors by piercing through the $O_2$ optode at selected sites. We measured depth profiles of 5 mm in 500 µm steps around the roots, in the rhizosphere, and in the bulk soil. Root growth was monitored by photographing roots and analyzed using RootPainter software. Surface $N_2O$ fluxes were determined every two to three days using transparent chambers and a LI-COR Trace Gas Analyzer. Soil moisture ranged between 70 and 80 % water-filled pore space and was monitored by volumetric water content sensors and weighing of the rhizotrons.

## Upscaling $N_2O$ emissions from field to farm scale with ecosystem flux measurements and remote sensing

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### Abstract

Nitrous oxide ($N_2O$) is one of the most important anthropogenic greenhouse gases. The intensive use of nitrogen fertilizers caused an increase in $N_2O$ emissions over the last decades. Together with soil microclimate, fertilization is typically discussed as the main driver of $N_2O$ emissions and has thus been the focus of previous studies. Recently, the significance of plant performance driving $N_2O$ emissions was demonstrated in grasslands and croplands[1,2]. However, the spatio-temporal variability and the interactions of multiple drivers of $N_2O$ emissions are less clear.

In our project, we combine management, soil climate and remote sensing products to upscale $N_2O$ emissions to multiple fields in an on-farm study. We will a) quantify $N_2O$ fluxes, b) determine its drivers from cropland and temporary grassland, c) investigate soil N dynamics in response to management and environment, d) upscale $N_2O$ emissions from field to farm level, and e) evaluate and develop management recommendations to mitigate $N_2O$ emissions.

We will use i) the eddy covariance method to measure ecosystem scale $N_2O$ fluxes, ii) assess dynamics of distinct N pools in the soil plant system in relation to the environment and management, and iii) use satellite derived vegetation indices as well as vegetation assessments and soil sensors to upscale $N_2O$ fluxes from field to farm scale with empirical models. The results of this project will contribute to a better understanding of the spatio-temporal dynamics of $N_2O$ emissions under field conditions and provide a selection of site-specific management options to reduce $N_2O$ emissions from agriculture.

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## Exploring N2O Emission Drivers in Mixed Grass/Clover-arable Crop Rotations

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### Abstract

Over 60% of anthropogenic nitrous oxide ($N_2O$) emissions originate from agricultural soils, primarily driven by nitrification and denitrification. Yet, the influencing abiotic factors are still under-investigated. A 12-month experiment started in April 2023 at Foulumgaard Experimental Station (Denmark) to investigate drivers of $N_2O$ emissions. This experiment was conducted within a long-term experiment with six-year crop rotations with two or four years of grass clover (GC). Surface $N_2O$ emissions were measured in the rotation years preceding and following GC, where spring barley is cultivated (preGC-2yrs, postGC-2yrs, preGC-4yrs, postGC-4yrs, respectively, n=2, total: 8 plots). Furthermore, $O_2$ and $CO_2$ sensors were placed at 1 and 20 cm depth, while side-port needles to measure N2O were positioned at five soil depths (1-30 cm). Preliminary results show highest $N_2O$ fluxes post- fertilization and post-plowing in all treatments (April 21- May 31). Additionally, irrigation and freeze-thawing led to increased $N_2O$ emissions. The cumulative $N_2O$ emissions decreased in the order postGC-2yrs, preGC-4yrs, postGC-4yrs, and preGC-2yrs with 420, 341, 252, and 249 mg $N_2O$-N $m^{-2}$, respectively. After May, $N_2O$ concentration increased with depth, reaching a minimum of 0.06-1.81 µl/l at 1 cm, which were 59-67% and 62-70% lower than at 20 cm and 30 cm, respectively. In the presence of crop residues at 20 cm, higher $CO_2$ levels (exceeding 0.1%) and lower $O_2$ levels (0.3-23.8%) were observed. This indicates that environmental and management factors intricately influence $N_2O$ production and emissions. Subsequently, a more comprehensive investigation into the specific impacts of these factors on $N_2O$ dynamics will be focused on.

Do process-based models capture the effects of root traits on N losses?

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## Abstract

Efficient root traits in crops are an emergent focus on the potential impact of climate change on crop production, options for adaptation, and greenhouse gas mitigation. However, it remains unclear to what extent root traits can reduce nitrogen (N) losses such as nitrous oxide and nitrate leaching. Process-based models have been used extensively to identify desirable yield-related traits, but they have been seldom used with the perspective of reducing N losses in response to changes in root traits. To address these knowledge gaps, we synthesized the current knowledge regarding the relationships between root traits and N losses based on experiments from the scientific literature, and studied the capacity of four process-based models, i.e., DNDC, DSSAT, Daisy, and APSIM, to capture the interactions between root traits and N losses. The results show that the interactions between N losses and root traits differed in both magnitude (up to 30% difference) and direction between experiments and process-based models. We recommend model improvements that are required to overcome these shortcomings, such as developing 3D root components and integrating phenotyping and functional gene detection into process-based models. Overall, this research represents a key step towards designing a new generation of crops adapted to reduced fertilizer inputs.

## Enhanced deep N uptake by root niche differentiation can coexist with enhanced total N supply in clover-grass leys

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### Abstract

Introduction

Competition between species can stimulate deeper roots to increase N uptake from deeper soil and enhance recovery of N which has leached below the topsoil. However, it is unclear how enhanced N nutrition affects deep N uptake by roots of grasses in mixture with N-fixing legumes.

Aims To explore the contribution of vertical root niche differentiation to recovery of deep N by species in cultivated grass-clover leys.

Methods We developed a novel slow-release $^{15}NH4^{+}$ label placed at 42 cm soil depth and tracked the recovery through a whole growing season by seven species cultivated in mixtures or as monospecific leys. All leys received N fertilization (20 g $m^{-2}$ $y^{-1}$)

Results Ley mixtures with Trifolium pratense enhanced N yield by about 10 g $m^{-2}$ $y^{-1}$ compared to grasses in monospecific stands, and most grass species presented strong positive diversity effects on total N concentration compared to performance in monospecific stands, while diversity effects on deep $^{15}N$ uptake varied. Schedonorus arundinaceus, Schedonorus pratensis and Lolium perenne displayed positive diversity effects on deep $^{15}N$ uptake, however Phleum pratense and Poa pratensis did not. The sum of the positive diversity effects on deep $^{15}N$ uptake was stronger than the negative effects and mixtures overyielded compared to what was expected from monospecific stands.

Conclusions Improved N nutrition in grasses due to clovers did not prevent positive diversity effects on deep N recovery. This is potentially beneficial for reducing N leaching off-season. Diversity effects were species-specific and could not be predicted by performance in monoculture.

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## Higher risk for nitrous oxide emissions from spring-seeded compared to autumn- seeded crop

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### Abstract

Agricultural soils are considered to be a main source of global nitrous oxide (N2O) emissions, a potent greenhouse gas and dominant ozone depleting substance (Davidson & Kanter, 2014). Previous studies (Dobbie et al., 1999) together with recent observations under Danish conditions suggest that N2O emissions from autumn-seeded crops are less than from spring-seeded crops after nitrogen (N) fertilisation in spring. We hypothesise that winter crops with established root system remove fertiliser N faster than spring-sown crops, reducing the availability of N for microbial turnover and losses such as N2O emission.

A micro-plot experiment is conducted at Foulumgaard Experimental Station in Western Denmark to enable a direct comparison of N2O emissions from winter wheat and spring barley. A total of 16 metal frames, 0.088 m2, are arranged in a completely randomized block design with the following four treatments: (1) bare soil, no N fertilisation; (2) winter wheat receiving 40 kg 15N ha-1 as starter and 138 kg 14N ha-1 secondary; (3) winter wheat receiving 40 kg 14N ha-1 as starter and 138 kg 15N ha-1 secondary; and (4) spring barley receiving 138 kg 15N ha-1 at the time of seeding; in the fertiliser only nitrate-N is labeled. Soil N2O flux, mineral N dynamics and plant N uptake, and 15N signatures, will be monitored during the growing season. The 15N enrichment of N2O is followed in selected blocks with automated chambers interfaced with an LGR Isotope Analyzer. The results will support efforts to develop Tier 2 emission factors, and model development

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GHG emissions in irrigated maize-cover crop systems after long-term organic or mineral fertilization

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## Abstract

The study investigates management factors affecting "on-" and "off-" season soil greenhouse gas (GHG) emissions in an irrigated maize (Zea mays) -cover crop system on a long-term fertilization experiment. The experimental set up was stablished in a littoral Mediterranean environment (Northeast Spain) in 2014, with three replicated plots (3 m x 25 m) in random blocks, The top-soil was sandy-loam with 8,3 pH and 1,22 % organic matter content. Rainfall and mean annual temperature (1990-2020) are 644 mm and 14,5 °C, respectively. Maize fertilization treatments since 2014 consisted in the application of mineral fertilizer, pig slurry or digested cattle slurry at a target dose of 170 kg N $ha^{-1}$. GHG ($CH_4$, $CO_2$ and $N_2O$) fluxes were monitored during the maize crop (on-season) in 2022 and 2023 following the static chamber methodology in two replicates per treatment. Flood-irrigated maize for silage was sown in April and harvested in August both years. Mustard (Sinapis alba L.) as a pure stand or in a mixture with a legume (common vetch, Vicia sativa L.) was grown in subplots (3 m x 8 m) of each fertilization treatment during the off-season period (September-March). GHG measurements were performed in two replicates of each of the cover crop subplots. Seasonal and post-seasonal management differently affected cumulative soil $CO_2$ and $N_2O$ emissions, while no $CH_4$ fluxes were detected. Preliminary results showed that annual soil GHG emissions were most dependent on fertilization type, that influenced both, the amount of the emissions and its temporal dynamics.

## Quantifying Nitrogen Losses from Bio-Based Fertilisers in European Agriculture

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## Abstract

The increased environmental concern has promoted interest in circular solutions like recycling nutrient-rich side streams into biobased-fertilizers (BBFs). With the EU's new Fertiliser Regulation, BBFs can compete with synthetic mineral fertilisers, potentially reducing resource depletion. However, their environmental impact, especially nitrogen (N) losses compared to mineral fertilisers, remains uncertain. This study aimed to quantify potential emissions of reactive N from various BBFs through experimental and modelling approaches. Experimental results showed that potential ammonia losses varied greatly (0-64% of total N) among 39 N-rich BBFs and their characteristics (pH, NH4-N, NO3-N, dry matter, C:N) explained 89% of the variation. Incorporation of BBFs into soil effectively reduced potential ammonia loss by 37%–96% compared to surface application[1]. The N leaching losses from application of eight BBFs were simulated with a soil-plant-atmosphere model[2] for six diverse European cropping systems[3]. Across all cropping systems, N leaching primarily depended on total BBF- N input rates. If BBFs were applied at the same total N input rate as the mineral N fertiliser (assuming 100% mineral fertiliser replacement value, FRV), N leaching was similar or lower with BBFs. However, higher BBF total N input (assuming FRV <100%, derived from 1-year field trials) led to significantly higher leaching across all cropping systems. These findings highlight that the environmental implications of substituting mineral fertilisers with BBFs depend largely on their physico-chemical characteristics and FRVs. Continuous use of BBFs with low FRVs may increase N losses. To mitigate this, BBFs should either partially replace mineral fertilisers or not be applied annually.

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## Residual fertiliser-N denitrification losses over summer fallow period under different episodic rainfall intensities

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### Abstract

The legacy effect of nitrogen (N) fertiliser is a scarcely considered input in crop production systems, with productivity gains of applied fertiliser N beyond the year of application rarely accounted for. The paucity of studies capturing the scale of N losses and measurement of residual fertiliser in cropping systems between seasons, together contribute to persisting uncertainty around the fate of unused N fertiliser beyond crop maturity. Misalignment in timing between crop N demand and supply are recognised as opportunities that exacerbate N loss potential (Angus & Grace, 2017). One period of misalignment that receives little attention is the fate of applied N in seasons when split N application occurs late in the season and is coupled with a dry finish. Low soil moisture limits crop access to the applied N to form favourable conditions for fertiliser N to be retained in the surface soil at crop maturity. Wallace et al., (2020) recorded as much as 62% of applied fertiliser remained in the surface soil at crop maturity when application occurred late in the season with an absence of end of season rainfall. We conducted a field experiment at two Victorian cropping sites simulating high residual fertiliser-N remaining in the surface soil profile at the start of the summer fallow period, with two summer rainfall patterns. The study aimed to; (1) investigate the fertiliser-N denitrification losses across the summer fallow period and (2) investigate how temporal variation to soil moisture dynamics influence the denitrification product ratio ($N_2$:$N_2O$) and magnitude of loss at the two cropping sites.

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# Soil $CO_2$ and $N_2O$ fluxes under wheat and barley in a conventional vs reduced tillage trial in Germany

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## Abstract

Reduced tillage promotes soil organic carbon sequestration compared to conventional tillage under specific soil and environmental conditions. However, reduced tillage might also lead to higher $N_2O$ emissions from soils, thereby compromising its greenhouse gas (GHG) mitigation potential via soil organic carbon sequestration. In this study, we monitored soil $CO_2$ effluxes and $N_2O$ fluxes in a long-term conventional vs. reduced tillage field-trial with established higher topsoil organic carbon content under the reduced-till practice. The long-term tillage field-trial was paired with a 50% rain exclusion experiment with rainout-shelters established in 2023. GHG flux monitoring occurred in 2022-23 under winter wheat cultivation and in 2023- 24 under winter barley cultivation. GHG measurements were accompanied with frequent soil samplings for mineral nitrogen and dissolved organic carbon (DOC) determination especially after agricultural management events. Based on preliminary results from the winter wheat period, soil mineral nitrogen contents were higher in conventional-till than in reduced-till fields after fertilization events, while DOC was not affected by tillage practice. Rain exclusion did not affect soil mineral nitrogen or DOC contents. Regarding GHGs, soil $CO_2$ efflux was higher in conventional-till than reduced-till fields but this difference was not detected under rain exclusion. In contrast, soil $N_2O$ emissions were lower in conventional-till than reduced-till fields and this difference was significant only under rain exclusion. Reduced tillage presents trade-offs between crop yield, soil organic carbon sequestration and nitrogen dynamics. Therefore, reduced tillage evaluation for carbon sequestration should consider all relevant aspects of agricultural systems and their potential response to climate change.

## Comparing N2O emissions from organic and mineral fertilizers across different soil types and cover crop management strategies – an LCA comparing Daisy simulations and IPCC standards

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### Abstract

Nitrous oxide (N2O) greenhouse gas emissions (GHG) from fertilizer use is an environmental concern. The ongoing debate around the effect of mineral and organic fertilizers on N2O emissions, questions how we can design agricultural production towards achieving both the environmental and production goals in Denmark.

Quantification of N2O emissions and environmental impacts from organic and mineral fertilizers across different soil types and using different cover crop strategies, is a key research gap. Field trials are necessary for quantifying such differences but have physical and economic limitations. To develop policies and GHG accounting, such as the IPCC standards (Tier 1 emission factors), simplistic linear models, with potentially large deviations from actual emissions, are used.[1]

Calibration of dynamic simulation models such as Daisy[2], can allow for more accurate predictions on N2O emissions from nitrification and denitrification, resulting in Tier 2/3 emission factors of each fertilizer under different conditions. Such more differentiated emission factors can be applied in Life Cycle Assessment (LCAs) to calculate the ecological footprint of organic and mineral fertilizers.

Daisy is currently not able to predict N2O emissions accurately but will be tested against measured data to predict some general N2O dynamics.

The aim of this study is (i) To compare simulated N2O emissions from organic and mineral fertilizer across different soil types, with varying application rates and cover crop management strategies (ii) To compare the effect of Daisy determined emission factors with the current IPCC standards, on the ecological footprint of mineral and organic fertilizers through an LCA.

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## Impact of land use on riverine nitrogen concentrations in the paddy-dominated Lake Hachiro watershed in Akita, Japan

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### Abstract

The Lake Hachiro watershed (894 $km^2$) is an agricultural region primarily composed of paddy fields, including the shallow eutrophic Lake Hachiro. To implement effective nitrogen management strategies aimed at reducing nitrogen loads, a comprehensive understanding of the nitrogen cycle within the watershed is essential. In this study, we present an overview of research on nitrogen cycling in the Lake Hachiro watershed. Firstly, to understand the impact of the main land use in the watershed on water quality, we investigated the relationship between nitrogen and SS concentrations in river water and the land use of the watershed. Water quality data for the main five rivers flowing into Lake Hachiro over a 40-year period were compiled and, their correlation with land use in the watershed was evaluated. The proportion of paddy fields in the watersheds of the main five rivers ranged from 9.3% to 25.5%. The seasonal patterns of TN, NH4+, and SS concentrations clearly demonstrated that all reached their peak values in May, showing a positive correlation with the proportion of paddy fields in the watershed. Conversely, NO3- concentrations decreased in June-July possibly due to denitrification, and subsequently increased during winter. The notable increase in TN concentration in May was likely influenced by the drainage of puddling water from paddy fields, indicating a close association with paddy field water management by farmers. Therefore, improving water management in paddy fields and exploring alternative management practices, such as smart agriculture, were considered to be effective measures for reducing nitrogen loads in the paddy-dominated watershed.

# The impact of long term compost application on soil $N_2O$ emissions

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## Abstract

Application of compost in cropland generally results in enhanced carbon sequestration (Tiefenbacher et al., 2021). However, compost application may stimulate the emission of soil-borne nitrous oxide ($N_2O$), a potent greenhouse gas. This trade-off may offset the climate change mitigation obtained via carbon sequestration. Our study investigates the impact of long- term compost application on soil-borne $N_2O$ emissions.

In the long term Bopact field trial installed by ILVO, compost has been applied yearly since 2010. The soil organic carbon (SOC) content has been measured every 4 years. Since May 2023, $N_2O$ emissions have been monitored weekly in both the compost and the control treatments. After application of cattle slurry and mineral fertilizer, potatoes were planted. Compost was applied in September after harvesting the potatoes. White mustard was sown as cover crop. Since potatoes are cultivated on rigdes, $N_2O$ was monitored both on the ridges and in the furrows.

After planting the potatoes, higher emissions were observed from the furrows compared to the ridges. This effect was only observed for a limited period, while by the end of the growing season higher emissions from the ridges were measured. The cumulative $N_2O$ emissions measured in the compost treatment were similar to the emissions observed in the control. Combined with the enhanced SOC content observed in the compost treatment, these results suggest the positive impact of compost application on climate change mitigation. Further, our results stress the need to monitor $N_2O$ emissions in winter periods, since significant emissions were measured during this season.

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# Foliar nitrogen fertilization as a tool to reduce agricultural soil $N_2O$ emissions: A field study

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## Abstract

Agricultural soils are a major source of $N_2O$, mainly caused by N fertilizer applied to the soil where microorganisms convert it to $N_2O$. Foliar fertilization provides an alternative way of supplying nutrients, where N fertilizer is sprayed directly on the leaves of the crop. Since foliar fertilizer is not applied to the soil, we hypothesize that using foliar N fertilizers can lead to lower $N_2O$ emissions compared to using fertilizers applied to the soil.

We measured $N_2O$ emissions using static manual chambers in a one-year field experiment with three foliar N fertilizers, split into seven applications, and pig slurry and granular fertilizer, applied to the soil in April. We observed an increase in $N_2O$ emissions from the granular and slurry treatments following application in April. The same increase in emissions was not observed for the foliar treatments, and emissions were generally low during the growing season, except from an increase following an irrigation event one day after a foliar application. Following harvest, we observed an increase in emissions from the granular treatment, which resulted in an overall higher cumulative emission from the granular fertilizer compared to the foliar fertilizers. This was probably due to fertilizer granules that were not dissolved until this time because of the dry summer. The study shows that foliar N fertilization has the potential to reduce $N_2O$ emissions typically observed following the application of high doses of N fertilizer in the spring and emissions from residual N after harvest. However, this needs to be further explored.

## Soil gas diffusivity as predictor of nitrous oxide emissions from intact soil

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### Abstract

Recent research has shown a strong link between relative soil gas diffusivity (Dp/Do) and nitrous oxide ($N_2O$) fluxes[1,2], suggesting Dp/Do is a better predictor of $N_2O$ than other soil moisture measures. We investigated relationships between gas exchange, N transformations, and $N_2O$ emissions using intact soil (0-8 cm depth) collected from a winter wheat field in March 2023. The cores were adjusted to one of four matric potentials (-15, -30, -50, or -100 hPa), and then Dp/Do and air-filled porosity were measured prior to incubation with one of four treatments: ammonium nitrate (AN) at 50 kg N $ha^{-1}$ (starter); AN at 50+100 kg N $ha^{-1}$; AN at 50+100 kg N $ha^{-1}$, the main dose containing the nitrification inhibitor 3,4- dimethylpyrazol phosphate (DMPP); and unfertilized control. The cores were incubated and $N_2O$ fluxes monitored during 35 days. The highest $N_2O$ emissions were observed at -15 hPa and 150 kg N $ha^{-1}$. $N_2O$ fluxes declined with increasing Dp/Do, and soil N dynamics indicated mainly aerobic conditions. A significant reduction in cumulative $N_2O$ was observed with DMPP (range: 45-74%). Dp/Do values below 0.02 have been reported as upper critical indicator for anaerobic conditions to develop, but within the four matric potentials Dp/Do ranged from 0.002 to 0.008 which was not consistent with $N_2O$ results, and we suggest there was clogging of pores at the soil surface. The results confirm the relationship between Dp/Do and $N_2O$ emissions but show that Dp/Do of intact soil should be used with caution for prediction of emissions and mitigation potentials.

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## Assessing Biochar $N_2O$ Mitigation Potential Across Soil Textures and Moisture Contents: An Incubation Study with a Laser Spectrometer

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### Abstract

Agricultural soils are one of the most dominant sources of atmospheric nitrous oxide ($N_2O$), a potent greenhouse gas and a significant contributor to stratospheric ozone depletion. Several biochemical processes can produce $N_2O$, but nitrification and denitrification are considered the main sources of soil-emitted $N_2O$. Mitigating soil $N_2O$ emissions poses a significant challenge due to the complex interplay of multiple factors, including oxygen, pH, nitrate and ammonia concentration, and labile carbon availability. Exchange of $N_2O$ between the soil surface and the atmosphere is controlled by gas diffusivity, which in turn is influenced by soil bulk density, porosity, and water content (Chamindu Deepagoda et al., 2019). This may explain the findings that denitrification dominates in fine-textured soils, while the coarser soils favor nitrification (Jamali et al., 2016). As a potential mitigation strategy, biochar amendment has been hypothesized to improve soil structure and alter gas diffusivity (Sun et al., 2013), but the complexity of interactions and contrasting outcomes following biochar application require further investigations. Importantly, the interaction of biochar in different soil texture and water content could provide useful information on $N_2O$ production/consumption. Our study will examine how straw biochar (600 °C) affects $N_2O$ emissions across different soil textures (coarse and fine) and water content levels. We aim to test the hypothesis that biochar has potential to mitigate $N_2O$ emissions in denitrification favoring conditions, high clay and moisture. Aerobic incubation will be conducted (March/April 2024) with packed soils under controlled conditions and emission measured in real time by a mid-infrared laser spectrometer.

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## Effects of cover crop diversity on soil water content and N2O emissions under controlled drought conditions

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### Abstract

Nordic agricultural production faces multiple challenges in a warming climate with changes in precipitation and an increased risk of prolonged droughts. Changes in water availability has severe effects on plant productivity and microbial activity, which are likely to modify nitrogen

(N) cycling and nitrous oxide (N2O) emissions. The use of cover crops in agriculture is one of the climate-smart practices that have multiple benefits, such as increasing SOC, reducing N losses, and increasing biodiversity. Still the question whether cover crops and their diversity increase resilience against drought, and how the combined effects of cover crops, their diversity and drought affect N2O emissions, remain largely unknown.

We study the combined effects of cover crop diversity and drought on cropland (oat) GHG emissions and belowground C and N processes. Rainout shelters are used to assess the effects of reduced rainfall on C and N dynamics and gaseous emissions. The N2O fluxes are measured with the manual dark chamber method twice a week during the growing season and once a week during off-season when possible. Soil temperature and water content are measured continuously, and soil is sampled for mineral N and total C and N analysis seasonally.

The preliminary results show that the soil water content in the treatments with eight undersown cover crops with oat is less affected by reduced rainfall than the treatments with oat only. Reduced rainfall also affects N2O fluxes, and this effect depends non-systematically on plant species diversity.

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Denitrification rates measured in streams and flooded riparian areas.

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## Abstract

Leaching of nitrate (NO3) from agricultural areas in Denmark can lead to excess nitrogen (N) concentration in ground- and surface waters. However, during transport to the sea, NO3 can be removed through denitrification, a microbial process which converts NO3 into dinitrogen (N2) with a risk of producing smaller amounts of nitrous oxides (N2O). How much NO3 that is removed by denitrification in streams and during flooding of riparian areas is uncertain. Therefore, to accurately predict this process will be an advantage for understanding N-cycling.

We used the Nitrogen Isotope Pairing Technique (Nielsen,1992; Audet et al, 2021) to measure denitrification in 15 streams and during periods with flooding of 3 riparian areas during a year constituting a dataset of 342 individual measurements. The denitrification rates found were 0.25±0.11 kg N $ha^{-1}$ $d^{-1}$ (winter half-year) and 0.57±0.14 kg N $ha^{-1}$ $d^{-1}$ (summer half-year) in streams, and 0.21 kg N $ha^{-1}$ $d^{-1}$ on the flooded riparian areas.

With streams stretching 83,183 km covering a surface area of 24,000 ha, the potential for N-retention is about 3500 tons N per year on a national scale. Considering that more than 95 % of the Danish streams have been channelized (Brookes, 1987), re-meandering streams and thereby increasing stream length, could possibly increase N retention substantially, making it a useful tool in limiting N leaching to the aquatic environment and coastal areas. Furthermore, allowing the temporary inundation of riparian areas by restoring natural hydrology could contribute significantly to reducing nitrogen losses.

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## Estimation of N uptake in autumn cover crops using UAV-mounted RGB camera and machine learning

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### Abstract

In the precipitative intense autumn and winter season in Denmark, a cover crop established in or after the harvest of the main crop is an effective measure to lower nitrogen (N) leaching.

The N uptake in the cover crops is furthermore an additional N source for the following crop and should be considered when the N fertilization scheme is made. In both cases quantification of N uptake, biomass production, and C/N ratio is important, and results have been promising when UAV (Holzhauser et al., 2022; Kümmerer et al., 2023) or satellite data (Goffart et al., 2021) has been used as the predictive method on specific dates in the autumn. The purpose of this study is also to predict N uptake, biomass production, and C/N ratio using a UAV-mounted RGB camera in a range of cover crops established at different times after harvest of the main crop. A calibration model will be developed based on RGB images and destructive samples analyzed for N, C, and biomass as response variables. This model will predict the different parameters on other flight days. The novel part of the current study is the prediction of biomass production, N uptake, and C/N ratio during the autumn growing season. A time-series analysis of growth is valuable information when we want to optimize sowing time, the choice of crop and especially to quantify the optimum N uptake capacity rather than N uptake at a specific time in the autumn.

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## Incubation study on the influence of soil moisture, rain and inhibitors on ammonia emissions after urea fertilizer application

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### Abstract

The agricultural sector contributes to 90% of the ammonia ($NH_3$) emissions in Germany with 7% originating from the application of synthetic fertilizers (Vos et al., 2022). To reduce $NH_3$ emissions after the application of urea-based fertilizers, numerous developments have been made the last years. A reliable method is the use of urease inhibitors applied with the urea fertilizer, delaying urea hydrolysis in soil (Wang et al., 2020). One important variable influencing urea hydrolysis is the soil moisture. Water is needed for the dissolution of urea granules and the transport of the urea into the upper most soil layer. Since the effect of soil moisture on $NH_3$ emissions is crucial, we conducted a lab experiment investigating the interaction of soil water content and rainfall after fertilizer application with urease- and nitrification inhibitors applied with an urea fertilizer on $NH_3$ emissions.

Preliminary results support the efficient capability of the urease inhibitor to reduce the $NH_3$ emissions across all water contents tested (between 10 and 25%). Although not as effective as the urease inhibitor alone, the combination of urease and nitrification inhibitor resulted in reduced $NH_3$ emissions. Low or high soil water contents decreased the $NH_3$ release compared to an intermediate soil moisture. Independent of the fertilizer type, rainfall right after fertilizer application reduced the $NH_3$ emissions significantly. $NH_3$ emissions decreased with increasing amounts of rain.

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## The study site affects the magnitude of $N_2O$ emissions but not the efficacy of mitigation strategies

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### Abstract

Vegetable production is often associated with high N surpluses, posing the risk of substantial N losses. The application of an optimized N fertilization system ($N_{opt}$), the use of nitrification inhibitors (NI) or the removal of N-rich crop residues (-CR) were shown to be efficient strategies to reduce $N_2O$ emissions from vegetable-cropped soils (e.g. Pfab et al., 2011, 2012; Seiz et al., 2019). We tested these strategies against a high N treatment (high N) as a reference N fertilization scenario at two sites with varying soil texture (silty clay versus sandy soil) representing intense vegetable production in southern Germany over 20 months covering two vegetable cropping seasons with lettuce, cauliflower, and broccoli.

Cumulative $N_2O$ emissions over 20 months were lower at the sandy site. They ranged between 4.7 (unfertilized control, sandy site) and 73.9 kg N $ha^{-1}$ (high N, loamy clay site) with the latter being mainly a result of extremely high $N_2O$ fluxes throughout the whole winter period in the second year. Despite the different magnitudes of the $N_2O$ emissions, the lowering in $N_2O$ was similar at both sites (40 and 36% $N_{opt}$ treatment, 40 and 46% NI treatment, and 84 and 60% in -CR, at the loamy clay and sandy site, respectively). The $N_2O$ emission of -CR at the sandy site was statistically not different from the one in the unfertilized control. Denitrification was identified as the main source of the $N_2O$ emissions at both sites.

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## Sensitivity of nitrogen losses to interannual climate variation in subtropical hybrid dairy systems

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### Abstract

Sensitivity analyses reveal that climate and soil water storage capacity explain variations in nitrogen (N) losses from pasture-based dairy farms in temperate New Zealand, as estimated by Overseer model (Tavernet, 2023). Humid subtropical climates allow sequences alternating grazed mixed perennial pastures with double-annual cropping for silage. Under these conditions, hybrid dairy systems combining grazing with confinement have proven highly competitive, yet their environmental impacts remain unknown despite their substantial N surplus (Stirling et al., 2021, 2024). We conducted a sensitivity analysis to assess varying climate parameters' impact on N losses, estimated by Overseer, in subtropical Uruguay's hybrid dairy systems. Overseer was parameterised with local soil and climate data to predict N leaching, volatilisation, and denitrification from the whole-farm and for areas under pastures and annual crops. To assess the impact of the large interannual variability in temperature, evapotranspirative demand and precipitation, farmlets (1,300 kg liveweight $ha^{-1}$) with a 45:25:30 ratio of grazing:silage:concentrate diets were simulated for 16 meteorological years. Leaching strongly correlated with drainage ($R^2$=0.86), while denitrification remained low and volatilisation high, both with minimal variation. Drainage primarily determined N losses partitioning. In dry years, volatilisation dominated N loss, shifting to leaching with increased drainage. Climate's impact on N leaching varied between grazed pastures and annual crops, with leaching increasing more rapidly with increased drainage in the latter. This study provides insights into N losses in hybrid dairy systems, emphasizing the importance of tailored strategies to minimize environmental impacts, considering the diverse spatiotemporal responses across different farmland uses and covers.

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## Site-differentiated assessment and efficacy of nitrification inhibitors as a climate mitigation measure in crop production: the joint project 'NitriKlim'

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### Abstract

Agriculture is responsible for around 80% of all nitrous oxide ($N_2O$) emissions in Germany, mainly by the use of nitrogen fertilizers. Emissions might be reduced by using nitrification inhibitors. For a reliable recommendation of inhibitors as a climate protection measure on a national scale, however, some open questions have to be clarified:

- Are the inhibitors equally effective in reducing $N_2O$ emissions at different sites in Germany?
- Is the reduction effect still relevant, when $N_2O$ emissions are evaluated on an annual basis or will there be an offset?
- Will repeated application of inhibitors result in long-term effects on the soil and will this influence the effectiveness of newly applied inhibitors?
- What effects are to be expected on the amount of nitrate leaching and associated indirect $N_2O$ emissions?
- How can yield, quality, fertilization management and the economic benefit be influenced by usage of nitrification inhibitors? What is the level of acceptance among farmers?
- Which negative environmental effects might occur, in particular on soil microbial communities, by substance leaching to the ground water or by triggering ammonia or methane emissions?

To address these questions a Germany-wide network of coordinated field and laboratory experiments is performed. All nitrification inhibitors available in Germany are used in combination with mineral and organic nitrogen fertilizers. The measurements performed cover greenhouse gas and ammonia emissions, nitrate and inhibitor leaching, as well as inhibitor effects on nitrification and the microbial community for short-term and long-term inhibitor application.

Finally, a comprehensive assessment of the use of nitrification inhibitors as a climate protection measure will be carried out.

## Nitrogen leaching measured with suction cups for up to 6 years in different crop rotations

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### Abstract

In order to illustrate the amount of nitrogen leaching in different soil types and crop rotations nitrogen leaching has been measured with suction cups in 6 different locations for up to 6 years in 30 field trials. Suction cups have been established stationarily in 1 meter's depth and field trials with increasing amount of nitrogen has been carried out.

The leaching is affected by precipitation, and a high precipitation gives a larger amount of percolation from the field. The leaching and marginal leaching at a standard N rate is significantly lower on clay soils compared to sandy soils, with an average at 16 and 30 percent respectively. This difference is due to a higher leaching on sandy soils where the precipitation throughout the winter generally is higher than on clay soils.

Different crop rotations shows different amounts of leaching, which is affected by soil type, pre crop, main crop, and autumn coverage. Especially after winter oilseed rape and maize grown on sandy soils the percolation is high, and it is found to be lowest in winter rye after winter rye. On clay soils a high leaching is found in winter oilseed rape, and after winter wheat and spring barley followed by winter wheat. The lowest leaching is found after sugar beets.

When looking across the different soil types the highest nitrate concentration is found in crop rotations with maize – spring barley – bare soil, and the lowest nitrogen concentrations from the suction cups are found in crop rotations with autumn coverage.

Potential Effects of Power Line Construction on Soil Nitrogen Mineralization

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## Abstract

The German energy concept for the future envisions an energy mix for generating electricity in which renewable energies will account for an 80% share by the year 2050. However, the German power grids are not equipped to transmit renewable energy across the country, and large infrastructure measures are required to lay high-voltage direct current (HVDC) underground cables for electricity transport. Trench digging, which causes soil disturbance, is one effect of installing these underground cables. Another effect is the heat emitted into the surrounding soil using underground cables. Unfortunately, the potential effects of construction measures and possible thermal losses on nitrogen mineralization have not yet been studied in detail.

In four field trials in Southwestern Germany, the impact of soil warming caused by underground cables and construction measures was investigated by comparing the three treatments: Heated trench, Trench, and Control. The construction work was completed in 2021, and experimental data has been collected since then. The experimental design distinguishes the impact of the construction (Trench) and heating effects (Heated trench) by comparing them with the undisturbed Control. Construction measures and soil warming significantly change soil properties such as temperature, water content, bulk density, etc. After finishing the construction work and before sowing, the $N_{min}$ increased by over 100 % in the Trench and Heated treatment. However, after the vegetation period, the $N_{min}$ in the Heated treatment was significantly higher than in Trench and Control. It is concluded that the rise in soil temperature increased nitrogen mineralization.

## Measures to reduce denitrification losses after slurry fertilization in crop cultivation

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### Abstract

Many methods for reducing N emissions after slurry fertilization have been proposed over the last years. Most of the mitigation measures, such as addition of acid to lower the slurry pH or injection methods, mainly aim at reducing NH3 emissions in the first place. To date, little information is available on the effects of such measures on denitrification losses in crop production. As part of the joint research project 'Measures to reduce direct and indirect climate-impacting emissions caused by denitrification in agricultural soils - MinDen', a three-year field study, based on the crop rotation maize - winter wheat - yellow mustard – maize, is being carried out at the experimental farm of the University of Göttingen, Germany. The field study assesses the impact of slurry application methods such as slot injection and drag hose, and different additives such as H2SO4 or nitrification inhibitor as DMPP (3,4- dimethyl pyrazole phosphate) on N2O emissions on a randomized block design. The poster provides an overview of the methodology as well as preliminary results of the N2O measurements carried out with static chambers.

## The impact of crops productivity and fertilisation on soil nitrogen cycle microbiome and gas emissions

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### Abstract

More nitrogen (N) is applied to agricultural soils as fertilisers than is removed through agricultural products, leading to N losses. This study explored the relationship between various crop types, soil N2O emissions, mineral N fertilisation rates and manure amendment through the analysis of abundances of N cycle functional genes, biomass production, nitrogen use efficiency (NUE) and soil physicochemical analysis.

The study was conducted on the IOSDV (International Organic Nitrogen Long-term Fertilisation Experiment) experimental field in southern Estonia, Northern Europe, spanning from April 2022 to October 2022. The study included three crop types (spring barley, spring, wheat, sorghum) and three mineral N fertilisation rates (rates 0, 80 and 160 kg N $ha^{-1}$). Additionally, farmyard manure amendment was studied.

We found that N2O emissions are primarily dependent on the mineral N fertilisation rate. Crop type did not significantly influence soil N2O emissions. The results indicate nitrification as the dominant process of soil N2O production in our experiment. Furthermore, the amendment of manure increased the number of N cycle genes that are significant in the change of N2O. Microbial analyses revealed a potential role of DNRA and comammox processes in soil N2O production. The study suggests an optimal fertilization rate of 80 kg N $ha^{-1}$ for wheat cultivation. Moreover, the findings indicate the potential for sorghum cultivation in temperate climate.

## Impact of over-winter sheep grazing cover crops on nitrate leaching losses from sandy textured soils in Lincolnshire, UK

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### Abstract

Grazing cover crops by sheep has the potential to provide additional farm income. However, there is a risk that grazing cover crops can damage soil structure leading to an increase in surface run off and soil erosion. Furthermore, the impact of grazing on nitrate leaching losses is not well studied. Field trials were set up in Lincolnshire, England on sandy loam soil to investigate the impact of grazing cover crops with sheep on over-winter nitrate leaching losses and spring soil structural condition. Ground cover treatments included 1) over-winter stubble (control) and 2) cover crop mixes which were both grazed and ungrazed. In the first trial, grazing commenced at the end of November; after 2-weeks all above ground biomass was grazed off. The second trial, compared different grazing timings (November versus February) with cover crops until ground cover was c.20%. Following grazing, nitrate leaching was measured from every treatment using porous ceramic pots with drainage volumes calculated using the IRRIGUIDE meteorological model. In general, cover crops were effective at reducing nitrate leaching losses compared to leaving ground in stubble over-winter. However, in the first trial grazing cover crops increased total nitrate leaching losses, by up to 35 kg NO3-N/ha compared to ungrazed cover crops. In the second trial, total nitrate leaching losses were just c.5 kg NO3-N/ha greater from the grazed compared to the ungrazed cover crops; with no difference in nitrate leaching losses between grazing timings. The results indicate that grazing cover crops can lead to increased nitrate leaching losses; however, grazing management strategies which aim to retain some ground cover are important to minimize the risk of N leaching

Does a soil drying-rewetting cycle decrease the effectiveness of nitrification inhibitors?

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## Abstract

Changes in soil moisture content can be an important factor influencing the effectiveness of nitrification inhibitors (NIs). Therefore, we hypothesized that a soil drying-rewetting cycle enhances biodegradation and decreases the effectiveness of NIs. This study evaluated the effectiveness of DMPP and MP+TZ (3-Methylpyrazol and Triazol) under a drying and rewetting cycle relative to low and high soil moisture conditions under two soil textures. NIs performance was assessed through measuring (i) daily and cumulative N2O-N emissions, (ii) soil $NH4^{+}$-N and $NO^{-3}$-N concentrations, and (iii) the composition of bacterial soil communities over the experimental period in an incubation study. NIs application reduced the overall N2O-N emissions under drying-rewetting (-45%), 40% water-holding capacity (WHC) (-39%), and 80% WHC (-25%). In general, the relative abundance of nitrifying bacteria Nitrospira spp., Nitrosomonas, Nitrobacter, and Nitrosococcus was reduced by DMPP and MP+TZ application, explaining the observed results. Unexpectedly, between days 30 and 60, DMPP and MP+TZ inhibitory effect on nitrification was weakened, and the N2O-N emissions from NI-treated soils increased by 5 to 6-fold relative to the control treatment in the silt loam soil at 80% WHC. These results indicated that DMPP and MP+TZ application can cause late increased N2O-N release due to short-term effects on the relative abundance of nitrifying bacteria and subsequent $NO3^{-}$-N accumulation. Thus, our study provided new insights into how the interaction between time and soil water content can decrease the effectiveness of NIs.

## Effect of reduced rainfall on $N_2O$ emissions in agricultural rotations with cover crops

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### Abstract

Cover crops can influence soil organic carbon sequestration and greenhouse gas (GHG) emissions. However, in a context of climate change with a greater risk of extreme events (e.g. prolonged droughts), it is not clear how cover crops could modulate nitrogen and carbon flows. Our objective was to evaluate the effect of reduced rainfall on nitrous oxide ($N_2O$) emissions in rotations of the Argentinean Humid Pampas. We installed rain shelters which exclude 50% of the natural rainfall in experimental plots from a long-term trial (2005-ongoing) with a maize-soybean rotation with and without cover crops (vetch and an oats+vetch mixture) under no tillage, and with inorganic N fertilization (32 kg $ha^{-1}$) applied to maize (experiment description at Restovich et al. 2019). The $N_2O$ emission measurements began immediately after maize sowing, on November 1$^{st.}$ 2023. Initially, treatments without rain shelters emitted more $N_2O$ than with rain shelters (212.8±36.2 vs 46.2±36.2 μg N $m^{-2}$ $h^{-1}$, respectively), and maize sown on treatments with cover crop residues emitted more than maize without antecessor cover crops (188.5±44.4 vs 11.4±44.3 μg N $m^{-2}$ $h^{-1}$, respectively).

After 17, 42 and 44 days since sowing, $N_2O$ emissions were similar between treatments with and without rain shelters and with and without inclusion of cover crops, with an overall average rate of 9.66±1.21 μg N $m^{-2}$ $h^{-1}$. These partial results are framed in the TRUESOIL project of the European Joint Programe (2022-2025) which explores trade-offs between carbon sequestration and GHG emissions, across agroecosystems with different crop rotations, soil types and climates.

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# Mitigating Nitrogen and Carbon Emissions in Industrial Tomato Cultivation through the Integration of Lablab purpureus L: A Study on Soil Health and Crop Productivity

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## Abstract

Industrial tomato production, a high-demand solanaceous crop, significantly depletes soil nutrients and contributes to increased nitrogen and carbon losses due to intensive agricultural practices. This study explores the potential of integrating Lablab purpureus L., a leguminous "forgotten crop", as a preceding intercrop to enhance soil fertility, reduce environmental emissions, and improve tomato productivity. Lablab purpureus L., known for its nitrogen-fixing ability and contribution to soil organic matter, was cultivated prior to the tomato planting season in selected fields. Soil analyses, phyto-sanitary indicators, and productivity metrics were collected and analysed across fields with and without the preceding Lablab purpureus L. cultivation. Preliminary results indicate that fields preceded by Lablab purpureus exhibited improved soil health, evidenced by increased nitrogen availability and higher organic matter content. Additionally, a significant reduction in nitrogen and carbon losses compared to standard tomato cultivation practices and enhanced tomato yields, suggesting that the improved soil conditions directly contributed to better crop performance. Phyto-sanitary indicators also showed a decrease in disease incidence and pest infestation in tomatoes preceded by Lablab cultivation, attributing to a healthier crop environment and reduced need for chemical inputs. This study underscores the potential of reintroducing forgotten crops like Lablab purpureus into modern agricultural systems as a sustainable practice to mitigate environmental impact while enhancing crop productivity. The findings advocate for a reevaluation of crop rotation and intercropping practices to include nitrogen-fixing legumes, offering a viable strategy for reducing the carbon footprint and improving the sustainability of intensive agricultural systems.

## Aknowledgements

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## Understanding how biochar properties modulate denitrification products in a calcareous soil

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### Abstract

Biochar (BC), the solid by-product of pyrolysis, has been proposed for reducing N2O emissions from soil. Multiple studies examining N2O emissions via the denitrification pathway have demonstrated a decrease in soil N2O emissions following BC amendment (Cayuela et al., 2013; Weldon et al., 2019). Nevertheless, this pattern does not universally extend to all BC-soil combinations, as increased N2O emissions through denitrification have also been observed. The underlying mechanisms behind these discrepancies remain elusive. We hypothesized that specific BC characteristics play a fundamental role and conducted a microcosm experiment to elucidate the key properties associated with increased N2O emissions. The $^{15}$N gas-flux method was used to investigate the impact of eight BCs on denitrification products (N2O and N2) in a calcareous soil. Results revealed that the influence of BCs on denitrification depended on the pyrolysis temperature. BCs produced at 400°C increased total denitrification by 28%, while those at 600°C reduced it by 53%. Interestingly, despite decreased denitrification, the selected high temperature BCs did not reduce N2O emissions due to a shift in the N2O/(N2 + N2O) ratio favoring N2O. Surface carboxylic groups on BCs strongly correlated with N2O emissions. High-temperature BCs showed potential to reduce total denitrification in calcareous soil, but caution is needed to prevent an increase in the N2O/(N2O + N2) ratio. This research underscores the importance of pyrolysis temperature and surface characteristics of BCs in modulating denitrification, providing valuable insights for optimizing BC applications in diverse soil environments.

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Co-application of biochar with synthetic fertilizers or nitrogen-fixing bacteria to reduce N losses in pointed cabbage cultivation.

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## Abstract

Several strategies based on the incorporation of biochar in mineral, organic, and biological N-fertilizers have been recently developed to reduce N losses while maintaining or increasing crop yields (Schmidt et al., 2021). In this work we investigated a cabbage crop fertilized with:

1) N-enriched biochar (obtained according to Castejón-del Pino et al., 2023), 2) co-application of biochar with N-fixating bacteria or 3) co-application of biochar with split synthetic fertilizer. We compared crop yield, plant N concentration, $N_2O$ and $NH_3$ emissions and the N-fixating biomarker nifH. The highest crop yield and N uptake were observed in N-enriched biochar and split synthetic fertilizer, whereas the application N-fixating bacteria with or without biochar did not show any significant difference compared to the control. The application of N-enriched biochar or biochar with synthetic fertilizer showed similar $N_2O$ and $NH_3$ emissions to split synthetic fertilizer. However, the application of raw or N-enriched biochar, even at a low biochar application rate (8.5 t $ha^{-1}$), significantly increased soil organic C concentration. Finally, the co-application of biochar with the N-fixating bacteria increased the nifH abundance in soil by 68% compared to the sole application of bacteria. The enhancement of these N-fixating bacteria was also observed in N-enriched biochar treatment.

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## Mitigation measures in crop production to reduce climate-impacting emissions from denitrification

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### Abstract

Gaseous emissions from denitrification cause nitrogen (N) losses, which are relevant to crop production and contribute to climate change in the form of nitrous oxide ($N_2O$) emissions from agricultural soils.

The joint research project 'Measures to reduce direct and indirect climate-impacting emissions caused by denitrification in agricultural soils - MinDen' comprises a range of approaches and methods to quantify $N_2$ and $N_2O$ emissions in laboratory studies and at the field scale.

Our objectives are:

- Regionalisation of N losses due to denitrification in Germany based on existing models.
- Determination of the effect of mitigation measures in crop cultivation on $N_2$ and $N_2O$ losses on the field scale.
- Evaluation of mitigation options on the model, laboratory and field scale, with focus on topsoil and subsoil layers of different soil types.
- Further development of denitrification models to improve the mapping of mitigation measures using existing and new field data.
- Testing of mitigation options for Germany using the improved models, taking into account yield, economic viability, technological requirements, $N_2O$ emissions, nitrogen use efficiency, N input heights, $NH_3$ emissions and nitrate leaching.

We provide an overview of the approaches and discuss first insights and findings after the first year of the project.

### Acknowledgements

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# A study of spatial patterns of soil nitrogen isotopes as proxy for nitrogen cycling and loss pathways

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## Abstract

To reduce nitrogen losses from terrestrial ecosystems, we need better information about preceding soil biogeochemical processes. These processes discriminate against the heavy stable isotope, $^{15}N$, thus, NH3, N2O or N2 emitted from the soil will be depleted in $^{15}N$, leaving the residual soil N pool enriched in $^{15}N$ (Robinson, 2001). In combination with e.g., carbon and nitrogen concentrations, studies in the isotopic composition of soil nitrogen provide in situ information about accumulated effects of current and past N loss processes (Mudge et al., 2014).

The aim of our study is to (1) visualize spatial patterns in N and C isotopes in soil and plants and (2) to investigate the correlation between soil isotope patterns and biogeochemical processes, e.g., greenhouse gas emissions as N2O. The study was conducted on two undulating crop fields in Eastern Denmark. Conditions in moist depressions in these areas favor denitrification (Elberling et al., 2023), why it was hypothesized that topsoil from depressions will be enriched in $^{15}N$ relative to adjacent areas. However, the opposite pattern was discovered, with a significant positive correlation between elevation and soil $\delta^{15}N$ ($p<0.01$ and $p<0.001$). What drives this pattern needs to be investigated further.

The next step is to examine isotope patterns across a landscape with varying land-use intensities, soil texture and topography, together with N2O flux measurements to investigate the correlations between these parameters in natural and managed soils. This will be done in Kattrup Wilderness (900 ha) in Western Zealand, DK.

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# AMMONIA EMISSION MEASUREMENTS FROM A SLURRY TANK WITH AND WITHOUT A SEMI-FLOATING COVER

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## Abstract

We present farm-scale ammonia (NH3) emissions from an uncovered circular open tank storing dairy cow slurry, obtained through continuous measurements conducted over a two-year period utilizing a non-intrusive method. Subsequently, following the installation of a semi-floating cover on the tank, emission measurements were continued for an additional year. The analysis of the data was structured to account for the primary influencing factors, namely natural crust formation and meteorological conditions.

Our findings demonstrate that the presence of a natural crust with a thickness of ≥ 10 cm, covering the entire surface of the slurry, resulted in a 57% reduction in emissions compared to the uncovered tank, thereby emerging as the predominant factor influencing emission levels (Kupper et al., 2021a). The formation of the crust was notably impacted by tank agitation and filling levels. Precipitation events led to reductions in emissions ranging from 64% to 86% compared to dry weather conditions, although these effects were sporadic and had minimal overall influence on total emissions. Elevated wind speeds and temperatures were associated with increased emissions.

In the covered storage state, average emission reductions of 37% and 54% were achieved during periods with and without a surface crust, respectively (Kupper et al., 2021b). The variability in NH3 emissions in response to the interplay of influencing factors underscores the importance of considering these factors when determining emission factors for inventory reporting. However, such comprehensive data remain scarce due to the resource-intensive nature of farm-scale measurements.

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## The indigenous abiotic and biotic factors both determine the efficiency of nitrification inhibitors in upland soils

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### Abstract

The use of nitrification inhibitors (NI) in agriculture can reduce nitrous oxide ($N_2O$) emissions and nitrate ($NO_3^-$) leaching, but their performance is often highly unpredictable. The influence of soil physicochemical properties and indigenous microbial community structure on the effectiveness of nitrification inhibitors remains unclear. Therefore, in this study, microcosm incubation experiments with 3,4-dimethylpyrazole phosphate (DMPP) as test nitrification inhibitor was conducted in six tested soils, and the indigenous physicochemical properties and nitrogen cycle-related microorganisms (nirK, nirS, nosZ, narG, amoA, amoB) were measured to elucidate the knowledge gap. The present results showed that in upland agricultural soils in the Northern China, the soil available phosphorus, organic matter, and total nitrogen exhibited a significant negative correlation with the DMPP inhibition rate in net nitrification rate ($P < 0.05$). The soil pH and electrical conductivity were significantly positively correlated with the DMPP inhibition efficacy in $N_2O$ cumulative emissions ($P < 0.05$). The efficacy of DMPP was also influenced by biological factors. The species richness and evenness of AOB and nirK-type nitrite reductase denitrifying bacteria were significantly and positively correlated with the DMPP inhibition of net nitrification rate ($P < 0.05$). Therefore, understanding the impact of soil physicochemical properties and microbial communities on nitrification inhibitors can assist in better selection and use of nitrification inhibitors, improving their inhibitory effects, and thus better managing soil nitrogen cycling and reducing nitrogen losses.

# Slurry sanitization by pH modification: impact on ammonia emissions after soil application

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## Abstract

Efficient and cost-effective sanitization of pig slurry can be achieved by pH adjustment, acidification or alkalinization [1]. It is known that slurry acidification have a positive effect on ammonia ($NH_3$) emissions after slurry application to soil but few is known about the impact of slurry alkalinization on such emissions. In the present study, pig slurry was sanitized using 4 different approaches: acidification to pH 5 using $H_2SO_4$ (Ac) and to pH 5.5 using $Al_2(SO_4)_3$ (Alum); alkalinization to pH 9.5 with KOH (Alk); Alk followed by neutralization to pH 7 (Neut). Three contrasting soils (a sandy soil, a sandy loam soil and a loamy soil) were amended with raw or treated slurry ( 50 mg of $NH_4^+$-N) and then incubated in an hermetic glass jar with an acid trap (20 mL of HCL 0.5M) to quantify ammonia emissions during 27 days.

Slurry acidification with Ac and Alum were equivalent to reduce $NH_3$ emissions in all soils considered. As expected, slurry alkalinization led to an increase of $NH_3$ emissions compared with raw slurry but such increase relies on soil properties with significantly lower increases observed in the sandy soil than in the loamy and sandy loam soils. Neut treatment allowed reducing $NH_3$ emissions compared to alkalinized slurry but also raw slurry.

It can be concluded that both Ac and Alum as well as Neut treatments allowed to sanitize slurry with positive impact on $NH_3$ emissions but that effects on $NH_3$ emissions relies on soil properties and enzymatic activities.

## Acknowledgements

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# NICCEE: Global Nitrogen Innovation Center for Clean Energy and the Environment

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## Abstract

The production of green ammonia from renewable energy has the potential to transform the transportation and agricultural sectors in the next twenty years. Green ammonia production not only offers a pathway to decarbonize the marine transportation sector but also enables decentralized fertilizer production. While this technology could significantly reduce the greenhouse gas emissions of many human activities, the widespread adoption of green ammonia could have significant impacts on the nitrogen cycle and lead to a substantial increase in the amount of reactive nitrogen introduced into the biosphere. Some projections estimate that the amount of nitrogen fixed by Haber-Bosch could triple from 140 TgN today to 450 TgN by 2050.

The recently launched Global Nitrogen Innovation Center for Clean Energy and the Environment, or NICCEE, initiative aims to address the challenges and opportunities posed by green ammonia and is coordinated by the UMCES Appalachian Laboratory (IP Dr. Xin Zhang). With contributions from 25 research and innovation institutions, NICCEE serves as an information hub, innovation platform, and education center. The initiative will leverage state-of-the-art cyberinfrastructure to monitor the lifecycle and effects of nitrogen in agriculture-food-energy systems, facilitate the co-development of technological and socioeconomic solutions with a broad spectrum of stakeholders, and nurture the next generation of scientists and innovators championing sustainable and climate-smart nitrogen management. We will present the project structure, main aims, challenges, and preliminary results.

NICCEE is funded by: U.S. National Science Foundation, U.K. Research and Innovation, and Natural Sciences and Engineering Research Council of Canada. Project link https://niccee.org/ ; Team members: https://niccee.org/team-members/

## Use of organic fertilization to mitigate $N_2O$ and NO emissions in drip-fertigated crops

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### Abstract

Drip fertigation (DF) and substitution of mineral by organic fertilizers have been suggested as effective alternatives to mitigate nitrous oxide ($N_2O$) and nitric oxide (NO) emissions (Sánchez-Martín et al., 2010; Guardia et al., 2017). In this experiment, the application of the optimal N rate with different combinations of fertilizers on melon (Cucumis melo L., year 1) and maize (Zea mays L., year 2) was evaluated: (T1) control without nitrogen (N) fertilization, (T2) 100% of N rate as manure at seeding, (T3) 50% as solid manure at seeding and 50% as urea at dressing by DF, (T4) 50% as manure at seeding and 50% as soluble organic through DF, (T5) 100% as urea at dressing by DF, and (T6) 100% as soluble organic fertilizer by DF at dressing. Both $N_2O$ and NO emissions, as well as maize and melon yields, were analyzed. There were no differences in $N_2O$ emissions between treatments in year 1, while in year 2 emissions increased in T2 (+136%) and T3 (+72%) compared to T5. In contrast, in year 1 there was a significant reduction in NO emissions in T1 (-36%), T3 (-54%) and T4 (-34%) with respect to T5, while in year 2 the maximum NO fluxes were observed in T2. This study shows that substitution of mineral fertilization by a combination of organic fertilizers (manure at seeding and water-soluble fertilizer through fertigation at dressing) is a good strategy for maintaining yields and low $N_2O$ and NO emissions in intensive drip-irrigated crops of Mediterranean agrosystems, thus being interesting for “Farm to Fork” strategy goals.

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# Mitigating denitrification losses through capturing the N-budget and comparing farm management strategies

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## Abstract

Denitrification is the major pathway through which nitrogen is lost from soils in the form of N2 and N2O. Fertilization of agricultural systems stimulates the soil nitrogen cycle, including denitrification, so that direct agricultural N2O emissions contribute 60% to global anthropogenic N2O emissions (Ciais et al., 2013). Achieving climate-smart agriculture means appreciating that greenhouse gas emissions are intertwined and involves tradeoffs. For example, reducing N2O emissions via nitrification inhibition can increase ammonia volatilization and decrease soil carbon sequestration (Guenet et al., 2021). It is therefore important to accurately quantify the entire nitrogen budget of a system alongside greenhouse gas fluxes. As part of the MinDen project, we are measuring the complete N-budget over a three-year crop rotation of maize-winter wheat-mustard-maize at three sites across Germany and comparing farm management systems. The overarching aim of this experiment is to directly measure nitrogen losses through denitrification for these sites and treatments. Treatments comprise different nitrogen application approaches, including mineral and organic fertilizers. We also provide means to inform/validate biogeochemical models which will calculate Germany-wide nitrogen losses from agricultural soils.

Here we present results from the first year at the Gießen site in which we are comparing the “drag-hose” method of fertilization with “slit-injection” technology, designed to minimize nitrogen loss and improve nutrient incorporation (Buchen-Tschiskale et al., 2023). In addition, we present a nitrification-inhibitor treatment. Unique to the Gießen site is an organically-managed field directly alongside a conventionally-managed and we present results comparing the N-budgets of these two systems.

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## 2.3 Session 3: Nitrogen recycling

## Drivers of $N_2O$ emissions and N cycling in rye-vetch cover crop mixtures

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### Abstract

The impact of cover cropping on nitrous oxide ($N_2O$) emissions is contingent upon the diversity of cover crop species and the specific cropping phase. We tested the response of $N_2O$ to these two factors through a pot experiment encompassing six treatments: control (absence of cover crop), pure vetch (Vicia villosa Roth), pure rye (Secale cereale L.), and mixtures comprising 33%, 50% and 66% of the sowing rate of pure rye paired with 66%, 50% and 33% of the sowing rate of pure vetch, respectively. After the cover cropping, the same treatments were arranged during the post-incorporation phase, including pots with roots and shoots and pots without shoots. During the cover cropping phase, root traits such as fine/very fine roots or root length density were negatively correlated with mineral N content and $N_2O$ emissions, which were much lower than those during post-incorporation. Mixing rye with vetch increased total dry biomass and N transfer to cereal plants. During the post-incorporation phase, dissolved organic N and nitrate contents increased with the higher vetch proportion. Emissions from shoots contributed on average by 31% to total $N_2O$ emissions, being lower than those from roots and soil (average 57%, with the highest values in control and vetch monoculture). We conclude that the seed proportion in legume-cereal mixtures serves as an effective tool to balance between the benefits associated with pure legume (increased total biomass, and C and N yields) and pure cereal (decreased $N_2O$ emissions and soil mineral N pool) cover cropping.

## Impact of liquid fraction of digestates and biochar on winter wheat yield and nitrous oxide emissions

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## Abstract

Liquid fractions of separated digestates and biochar derived from the solid fraction of biogas digestates are used as alternative N fertilizers and for long-term C soil storage, respectively. However, the impact of these amendments on $N_2O$ emissions and crop production are still under-investigated. In this field study, effects of different liquid digestates (untreated and acidified to pH 5, 6 and 7) and biochar treatments on $N_2O$ emission and fertilizer values were tested when used for a second fertilizer application in winter wheat. The biochar was either mixed with liquid digestate and applied on the soil surface, applied with liquid digestate, or applied with mineral N fertilizer on a loamy sand soil in Denmark. $N_2O$ emissions were measured using manually closed static chambers from April to June 2023. The bulk of $N_2O$ emissions occurred within two weeks after application. Cumulative $N_2O$ emissions were higher in acidified than untreated digestate, but not significantly (125-154 vs. 76 g $N_2O$-N $ha^{-1}$). Lowest emissions were measured in treatments with application of biochar and mineral N fertilizer which was significantly lower than mixing biochar into liquid digestate at 42 and 146 g $N_2O$-N $ha^{-1}$, respectively. Grain yield among treatments was not significantly different to mineral N at 150 kg N $ha^{-1}$. The fertilizer value of liquid fractions ranged between 56-77%, with higher values for acidified liquid digestate. The preliminary results indicate a beneficial effect of biochar on $N_2O$ emissions when combined with surface application of mineral N fertilizer. The experiment will be repeated in 2024.

## An innovative Soil Mesocosm to Study Effects of Moisture & NO on Trace Gas Fluxes

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### Abstract

This research examines how soil nitric oxide (NO) levels and moisture influence greenhouse gas fluxes between soil and atmosphere, using the newly developed the Automated Soil Mesocosm System (AU-MES). This system dynamically adjusts soil and headspace NO, measures gas fluxes, and monitors key environmental parameters.

Initial a brief phase of soil-only incubation experiments, we investigated the effects of soil moisture and NO concentration (400 ppbv) in both soil and headspace on gas emissions. Findings indicated that under low soil moisture (30% WFPS), nitrification processes were enhanced, resulting in increased emissions of NO (19.12 mg N $m^{-2}$ at zero NO and 18.02 mg N $m^{-2}$ at high NO) and NO2 (0.17 mg N $m^{-2}$ at zero NO and 0.14 mg N $m^{-2}$ at high NO). Conversely, at higher moisture levels (50% WFPS), there was a significant rise in N2O (14.88 mg N $m^{-2}$ at zero NO and 14.73 mg N $m^{-2}$ at high NO) and CO2 fluxes (12.18 g C $m^{-2}$ at zero NO and 11.01 g C $m^{-2}$ at high NO), suggesting an increased role of denitrification. These observations, particularly following soil rewetting and fertilizer application, demonstrate the complex interaction of soil NO levels, moisture, microbial activity, and gas emissions.

In summary, the AU-MES is instrumental for studying soil-atmosphere gas exchanges and the effects of environmental factors, providing key insights into nitric oxide's role in soil and trace gas dynamics.

**Keywords:** Automated soil mesocosm system, nitric oxide, gas concentrations, headspace purging, soil purging

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## The role of higher molecular weight dissolved organic nitrogen in the plant-soil nitrogen cycle

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### Abstract

The cycling of large size organic nitrogen (N) molecules from plants into stable microbial derived soil organic carbon (C) and N pools is poorly understood. We investigated the fate of peptide- and protein-sized organic N fractions in soils from two long-term field experiments markedly differing in conditions for microorganisms.

Triple-labeled dissolved organic N (DON) obtained from white clover shoots was separated into five different molecular weight (Mw) size fractions (>1 kDa). Two incubation experiments on soils with different long term management history were conducted. The first incubation experiment, soil from six different treatments were incubated with DON, using four different Mw size fraction and five different sampling times. The second experiment, three different soils, with and without a growing maize, were incubated with one DON fractions (>100 kDa) for 48 hours.

We demonstrate that depolymerization of proteins is not the rate limiting step in the turnover of organic N, neither is sorption of protein-sized organic N to the soil mineral phase. We also provide strong evidence that C and N from labile compounds persist in soil due to incorporation into microbial cell walls via anabolic processes.

In the second experiment, we estimated that at least 20–30% of the N uptake occurred in organic form, based on the $^{13}C$:$^{15}N$ uptake ratio in the maize plants. We also saw that more amino acids remained in soil with than without maize, suggesting a greater incorporation of amino acids into the microbial biomass, when an alternative C source was available for microbial respiration.

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## High importance of organic fertilizer N for grassland plant N nutrition in the years following fertilization.

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### Abstract

We applied $^{15}N$ labelled cattle slurry over one year to pre-alpine grassland in order to study its importance for plant N nutrition not only in the year of application, but also in the four following years. This five-year $^{15}N$ tracing study was combined with a space for time climate change experiment in order to assess long-term fertilizer N cycling under current and future climatic conditions. In the year of $^{15}N$ fertilizer application, the recovery of $^{15}N$ in harvested aboveground plant biomass was as low as 7-17%, while fertilizer $^{15}N$ retention in the soil nitrogen pool was considerably higher (32-42%). In the year after its application, fertilizer was of equal importance for plant N nutrition compared to the year of application, as illustrated by a plant $^{15}N$ recovery of 9-14%. $^{15}N$ recovery in mowed plant biomass then only slowly declined in the following years and stayed significant over the entire 5 years monitored in this study.

After five years, the cumulative $^{15}N$ recovery rate in mowed biomass was 33 to 41 %. Considering $^{15}N$ recovery in soil and roots after 5 years revealed a total $^{15}N$ tracer recovery of 66% for the climate change treatment and 77% for the climate control treatment. These results show a rapid cycling of nitrogen through soil organic matter until remineralization and plant uptake. Furthermore, we reveal a minimal contribution of recent fertilizer nitrogen to plant nutrition and the dominance of soil organic nitrogen over fertilizer nitrogen for plant nutrition in such grasslands. The findings reinforce the concept that fertilizing such grasslands is largely a fertilization of soils rather than a fertilization of plants, thereby replenishing mineralized soil organic nitrogen (SON) stocks that is exported by harvests. Particularly under climate change conditions, the low N recovery rates of plant nitrogen, high plant N export and the rapid remineralization of soil organic nitrogen led to negative nitrogen balances.

## Reduction of mineral fertiliser use and contribution to a circular economy with RENURE

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### Abstract

The Flemish agricultural sector is having a surplus of animal manure while additional nutrients in the form of synthetic mineral fertilisers are still being supplied, as the Nitrates Directive (91/676/EEC) limits the use of animal manure to 170 kg N ha-1 year-1. RENURE (Recovered Nitrogen from manure), for example ammonium salts, can contribute to a circular economy as alternatives to synthetic fertilisers.

Field experiments were conducted with ammonium nitrate (AN) from ammonia-stripping on farmers' fields in maize, potato and winter wheat inspired by the principle of 'on-farm experimentation' (Lacoste et al., 2022). This entails that AN was applied in wide strips instead of synthetic fertiliser the farmer normally uses, on top of 170 kg N ha-1 of animal manure. Strips following the farmers' practice (reference) and strips with AN alternated each other. AN proved to be a valuable fertiliser, performing as well as its synthetic counterparts when applied in the same dose. While the tests proved the agronomical value of RENURE, there were some bottlenecks. The products contain lower percentages of nitrogen than synthetic fertilisers and they still have a status of animal manure.

To address this, follow-up projects are carried out focusing on blends of RENURE products, to cater to nutrient needs of crops. Additionally, experiments are being set up in greenhouse crops (chicory, strawberry and tomato) where typically only synthetic fertilisers are being used. First results will be known during spring 2024. Introducing RENURE in these cultivation systems would be a big step forward towards a circular economy.

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Using marine polychaetes to recycle nitrogen rich marine fish farm waste.

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## Abstract

Finfish aquaculture continues to expand globally with this expansion, waste is produced in proportionate amounts. Recirculating aquaculture systems (RAS) are land-based finfish hatcheries that produce hundreds of tonnes of waste annually (Dauda et al., 2019). This waste is currently treated and transported to arable farmland in Scotland where it is spread as fertiliser increasing the carbon footprint of RAS operations and releasing $N_2O$ as it degrades. This is an often-overlooked source of greenhouse gasses which adds significant cost to the operations of Scottish aquaculture. Here, we present a novel technique for using marine polychaetes to recycle fish farm waste, closing the nitrogen loop and converting potentially harmful waste into marketable protein.

Marine polychaetes, a diverse group of segmented worms, are capable of bioremediation and nutrient cycling in aquatic environments (Jerónimo et al., 2020). The Nitrofellow project aims at utilizing the potential of marine polychaetes to convert this waste and source of greenhouse gasses into a marketable biomass. In an ex-situ aquarium set up we aim to test how marine polychaetes can consume aquaculture waste and convert it to protein, resolving the release of $CO_2$ during transport of waste, and $N_2O$ once the waste is spread to land.

Initial trials have shown that significant biomass is gained in ex-situ tanks resulting in the reduction of waste in a chemical free, biological way. This system not only presents a potential solution to the release of greenhouse gasses but reduces the cost of waste disposal for aquaculture systems.

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Impacts of changes in manure management on nutrient losses in Quzhou City, China

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## Abstract

In China, the rise in livestock numbers has generated a large amount of manure (3.8 billion tons annually). Despite its huge potential for cropland fertilization, the average manure recycling rate is lower than 40% and a substantial amount of nutrients is lost to air and waterbodies (Jin et al., 2021). Addressing these nutrient losses through improved manure management presents a high opportunity for enhancing nutrient recovery. To date, hardly any studies have quantified the separate and combined impacts of changes in manure production rates, manure recycling rates and manure treatment technologies on nutrient availability from manure and related nutrient losses. In this study, we did such an analysis using Quzhou City, China, as the study area. Quzhou is a major city for livestock breeding in Zhejiang province, primarily focusing on pig and poultry production. From 2011 to 2020, Quzhou shifted from traditional to industrial livestock production, alongside advancements in manure management and enhanced manure recycling. We first quantified the combined impacts of changes in livestock numbers, manure recycling rates and manure treatment technologies on crop nutrient availability and nutrient losses during this period. Preliminary results showed that improved manure management increased nitrogen recovery from poultry production by 15% and reduced nitrogen losses from housing systems and field application by 8%. We then performed a scenario analysis for possible trends from 2021 to 2030 while separating the impacts of changes in livestock numbers, manure recycling rates and manure treatment technologies and then combining them. Results will be presented during the conference.

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## Spatial patterns of current ammonia emissions from agriculture using a newly developed bottom-up method in China

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### Abstract

Atmospheric ammonia ($NH_3$) is an important component of the nitrogen cycle in the earth. However, uncertainties in emission totals and in the spatial variation in agricultural $NH_3$ emissions is still quite high in China. In this study, an advanced bottom-up ammonia emission model for agricultural cropland and livestock management for China (AMEMCHIN) is developed through deriving ammonia emission fractions as a function of fertilizer type, crop type, soil properties and climate from 2418 field experiment data.

AMEMCHIN is then applied to derive a 1km x 1km resolution agricultural $NH_3$ emission inventory in 2017 based on 2785 county-level activity data of different livestock and crop types, combined with excretion rates per livestock type, fertilizer inputs per crop type, climate data and soil properties, either downscaled or available at 1km x 1km resolution. Downscaling of livestock was based on forward stepwise regression model considering impact factors of land use, geomorphology, climate, and population distribution. Results show that The ammonia emissions thus estimated for the year 2017 from China's cropland were 4.2 Tg $NH_3$–N in the year 2017, of which paddy rice accounted for 18%, and maize and wheat contributed 23% and 13%, respectively. The total $NH_3$ emissions from manure generated by livestock production in 2017 were 5.7 Tg $NH_3 yr^{-1}$, and the major sources were, dairy cattle (31%) pigs (29%), and poultry (23%), while donkeys, horses, and mules had smaller contributions. Emission hotspots primarily come from North China Plain and Northeast China Plain.

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J. Sci. Commun. 163, 51–59. https://doi.org/10.1016/j.Sc.2010.00372.

# From Pee to Fertilizer using Partial Nitrification and Sequential Batch Operated Pulsed Electric Field Electrodialysis

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## Abstract

Source-separated human urine holds significant relevance for nitrogen recycling, offering a sustainable solution to nutrient management in agriculture and reducing dependence on synthetic fertilizers. As populations grow and environmental concerns intensify, harnessing the potential of urine as a resource becomes imperative for sustainable development. Current state-of-the-art processes are the VUNA process (with its product Aurin) and the French based Toopi's fermentation method. However, these methods entail drawbacks, with the Aurin process incurring high energy costs due to distillation and activated carbon usage, and Toopi potentially facing challenges in scalability or resource efficiency.

Building upon the pioneering work of De Paepe et al. (2018) and predecessors like Pronk et al. (2006), our research aims to advance nitrogen recycling from source separated urine further. We enhance nitrifier efficiency through improved aeration, homogeneous sludge mixing, and better control over sludge age. By addressing these factors, we aim to optimize nutrient conversion rates and reduce operational costs. Additionally, we aim to elevate the performance of Electrodialysis Reversal (EDR) technology through innovative approaches. These include implementing a unique reverse Pulsed Electric Field (PEF) to reduce membrane fouling and micropollutant breakthrough, optimizing energy consumption through process redesign, and achieving higher concentrations of mineral concentrates through improved process control and selective ion transport mechanisms.

By combining advancements in biological and electrochemical treatment processes, our research promises to push the boundaries of nitrogen recycling efficiency and resource recovery. The production process and quality of the urine mineral concentrate product will be presented, as part of the PPS project KNAP on recycled fertilizers from wastewater: https://www.wur.nl/en/project/pps-project-closing-the-cycle-of-nutrients-from-wastewater- and-process-water-knap.htm

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# Future impacts of eutrophication on global freshwater fish biodiversity

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## Abstract

The increased application of synthetic fertilizers and population growth have markedly elevated the emissions of nitrogen (N), and this trend will continue towards the future (Mogollón et al., 2018). N enrichment can induce eutrophication, causing detrimental impacts on water quality and exacerbating the decline of species. Considering diverse environmental conditions, nutrient limitations, and species responses, eutrophication impact varies spatially, and thus a region-specific evaluation is necessary. Here, we assess future biodiversity loss caused by eutrophication across different socio-economic pathways (SSPs). We employed Life Cycle Assessment methods to measure the regionalized contribution of various emission routes across different SSPs. Our results reveal that N contributes significantly to the potential global species loss of freshwater fish. In particular, the agricultural sector emerges as the primary contributor to eutrophication-induced ecosystem impact, surpassing other sectors. The potential loss of fish biodiversity poses a threat to a wide range of regions and economies, especially the hotspots in Brazil and China, emphasizing the need for policymakers to take proactive steps in addressing the implications of eutrophication on freshwater biodiversity. This study underscores the urgent need for coordinated actions to achieve Sustainable Development Goals 6.3 (improve water quality) and 15.1 (ensure sustainable freshwater ecosystems), as well as Kunming-Montreal Global Biodiversity Framework target 7 (reduce pollution's impact on biodiversity). Consequently, our findings can assist in the development of management strategies for anthropogenic N emissions in emission pathways.

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How realistically do Earth System Models recycle nitrogen?

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## Abstract

Many Earth System Models (ESMs) simulate N limitation on terrestrial carbon uptake and some have implemented separate $NH4^{+}$ and $NO3^{-}$ pools to better represent inputs, losses and recycling of N. In this presentation, global rates and ratios of key soil N fluxes, including nitrification, denitrification, mineralization, leaching, immobilization and plant uptake (both $NH4^{+}$ and $NO3^{-}$) in two ESMs are evaluated against literature values, including global compilations and detailed site-specific values from the Hubbard Brook Forest in New Hampshire. The ESMs predict similar global rates of gross primary productivity (GPP) but have ~2 to 3-fold differences in their underlying global mineralization, immobilization, plant N uptake, nitrification and denitrification fluxes. Both models dramatically underestimate the immobilization of $NO3^{-}$ by soil bacteria compared to literature values and predict dominance of plant uptake by a single form of mineral nitrogen. One ESM, CLM5.0, strongly underestimates the global ratio of gross nitrification:gross mineralization and predicts a global ratio of nitrification:denitrification on the order of 2:1. In contrast, observations from Hubbard Brook suggest that nitrification may exceed denitrification by an order of magnitude. Modifications to the standard CLM5.0 indicate that a simultaneous increase in the competitiveness of nitrifying microbes for $NH4^{+}$ and reduction in the competitiveness of denitrifying bacteria for $NO3^{-}$ can bring soil N flux ratios into better agreement with observations. Greater scrutiny of the functional impact of introducing separate $NH4^{+}$ and $NO3^{-}$ pools into ESMs could help improve confidence in present and future simulations of N limitation on the carbon cycle.

# Circular and Nature-based Solutions for Improved Nitrogen Recycling in agricultural Landscapes

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## Abstract

This paper presentation is based on a real-world example from a watershed around central Limfjorden, Denmark. It is one of the most agriculture intensive areas in Europe, with high value livestock and crop productions systems combined with significant nitrogen (N) reduction targets set according to the EU Nitrates- and Water Framework Directives. Consequently, solutions to the problems faced in this area are of interest to many other areas around the globe, facing similar challenges with regard to reduced N pollution in combination with significant greenhouse gas emission reductions, biodiversity measures etc.

The evaluation takes its starting point in the Danish CIRKULÆR farming systems model, quantifying biomass flows in agriculture for a representative year in terms of required external input, turnover, products and losses. This is combined with local datasets, stakeholder interviews and scenarios developed in the parallel European research projects of MIBICYCLE, MIXED-project.eu and trans4num.eu, involving local networks of farmers, farm advisors, industry partners, municipalities, public agencies and other actors along the value chains for nutrient cycling in the area, to fulfil watershed N and greenhouse gas reduction targets set.

The suite of landscape scale measures from the UN-ECE Integrated Nitrogen Management Guidance Document[1] are discussed, including the assessment of more grass for protein extraction in biorefineries combined with biogas from plant residues and livestock manure in circular systems, organic farming systems, and the potentials and pitfalls for geographical targeted measures[2] in decision-making for more Nature-based Solutions, exemplified with green transition scenarios reaching N use efficiency and emission reduction targets.

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## Potential upcycling of waste from the agrifood chain in agriculture: A nitrogen recycling perspective

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### Abstract

Nowadays, a plethora of residual streams are generated from the agro-industrial sector causing environmental problems. Valorization of such residues in agriculture is a promising solution to recycle valuable plant nutrients, such as nitrogen (N) and phosphorus (P). Some residues can also be used as alternative additives to modify the pH of animal slurry that can be later used for fertilization [1]. The present work aimed to: (i) characterize residues from the agrifood chain and evaluate their potential as slurry pH-modifying agents; (ii) assess the potential N mineralization and (iii) biochemical and ecotoxicological effects after soil application of the studied residues and pH modified slurries.

Residues from the cheese, yeast and aquaculture industry as well and from a restaurant were collected and characterized for their physico-chemical properties. An experimental setup was established to explore their potential use in bio-acidification (pH 5.5) or alkalinization (pH 9) of pig slurry. A short-term incubation trial followed, to assess the potential N mineralization of the organic residues and pH modified slurries. Soil dehydrogenase activity and ecotoxicological evaluation using bioassays with terrestrial organisms, plants and earthworms (Eisenia fetida) will also be used, to assess the potential effects on soil health indicators.

First results showed that orange peels had a strong potential for slurry bio-acidification. Other results, still under analysis, are expected to provide valuable information about the nutrient upcycling in agriculture and identify potential risks associated with this practice.

### Acknowledgements

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## Promoting the use of slurry and compost as organic fertilisers in a large diversity of crops

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### Abstract

Manure valorisation as crop fertiliser presents a significant opportunity, especially given that between 2016 and 2019, the EU and the United Kingdom collectively produced 1.4 billion tonnes of manure annually [1]. In this project, pig slurry and composted poultry manure will be used as fertilisers for tomato and maize (silage and grain) production, as well as for various orchard crops, including apple and almond orchards, vineyards (for table grapes and for wine production), and olive groves. We will evaluate the impacts of this practice on greenhouse gas (GHG) emissions, soil fertility, crop yield, and other attributes such as leaf and fruit analysis, and weed biomass in orchard interrows. Additionally, we will explore the use of the liquid fraction of pig slurry in fertigation systems in the orchards. Baselines for comparison will include an unfertilised control and a mineral-fertilised control. Our expectation is that these solutions will not adversely affect crop productivity or silage production in terms of quantity and quality. Furthermore, we anticipate that they will enhance soil carbon (C) content, which holds particular significance in Mediterranean agriculture [2]. This impact also contributes to C sequestration, mitigating any potential increase in GHG emissions associated with manure application [3]. This project aims to demonstrate, on a large scale and across various crops, the valorisation of livestock byproducts, and the promotion of circular agriculture and nutrient cycle closure, thereby reducing nutrient loss, decrease reliance on mineral fertilisers, and improved management of livestock effluents.

### Acknowledgements:

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## Effects of Biochar and Hydrochar from Olive Mill Solid Wastes on Soil Fertility and Greenhouse Gas Emissions

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### Abstract

Mediterranean soils are usually poor in organic matter, therefore to maintain their soil fertility large amounts of fertilizers need to be applied. An inappropriate fertilizer application entails environmental impacts such as water pollution, soil degradation, or emissions of greenhouse gases (GHG) into the atmosphere. In parallel, large amounts of agricultural waste are generated yearly like olive mill solid wastes in Mediterranean areas. New technologies to valorize organic wastes have emerged such as biochar production where biochar and renewable energy are produced through pyrolysis or gasification. Recently, hydrothermal carbonization (HTC) has gained popularity in valorizing organic wastes with high water content where hydrochar is produced. Both biochar and hydrochar from different organic wastes, have been proposed as an advantageous strategy to increase soil C and improve soil physical and chemical properties (Rasse et al., 2022; Skryzupczak et al., 2023). Therefore, the valorization of olive mill solid wastes as fertilizers after biochar and hydrochar production can solve the problem related to their disposal, while part of the nutrients harvested can be returned to the soil enhancing the circular economy of the agroecosystems.

This work investigates the effect of biochar and hydrochar from olive oil solid waste on soil fertility and GHG emissions. For that, biochar from orujillo (dry olive cake), and biochar and hydrochar from alperujo (two-phase wet olive cake) will be applied in the soil in an aerobic incubation. Changes in soil physical, chemical and biological properties, and GHG emissions after biochar and hydrochar application will be presented at the Workshop.

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### Acknowledgement

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## Effects of organic and inorganic fertilizers on $N_2O$ emissions in 'Gala' apple orchards

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### Abstract

Nitrous oxide ($N_2O$) is a powerful greenhouse gas with an increased radiative forcing relative to $CO_2$ and about 80% of this gas is released from the agricultural fields where N is applied (Umar et al., 2023). Thus, there is a growing interest in more sustainable and ecological agricultural practices, such as replacement of mineral fertilizers with organic fertilizers.

The overall objective of this study was to evaluate the effects of organic based fertilization strategies, compared to a 100% mineral fertilization, on $N_2O$ emissions in a 'Gala' apple orchard, using static chambers. Four different fertilizations treatments were established (three replicates), aiming to supply 100 kg of plant available nitrogen per hectare: M1: 100% mineral fertilization throughout the crop cycle; M2: 75% mineral fertilization throughout the cycle + 25% organic fertilization (cattle manure) at bud break; M3: 75% mineral fertilization throughout the cycle + 25% organic fertilization (pig slurry) at bud break; M4: 50% mineral fertilization throughout the cycle + 25% organic fertilization (cattle manure) at bud break + 25% organic fertilization (pig slurry) at post-harvest. As expected, the higher $N_2O$ emissions were observed in all treatments during the apple growing period with a $N_2O$ peak observed in all treatments 28 days after application of manures. There is a clear trend towards higher values in the M1 treatment even if preliminary results (April 2023 to December 2023) indicated that the cumulative $N_2O$ emission in all treatments were not statistically different.

It can then be concluded that partial replacement of mineral fertilizers with organic fertilizers has no negative impact on $N_2O$ emissions in apple orchards.

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## Influence of fertilization strategies in 'Gala' apple orchard on leaf and fruit N content

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### Abstract

This study aimed to understand the effect of partial replacement of mineral fertilizers by organic fertilizers on nitrogen (N) content in the leaves and fruits of 'Gala' apple trees.

Four different fertilization strategies were established, in six different orchards (three replicates), aiming to allocate 100 kg of nitrogen per hectare: M1: control, consisted of 100% mineral fertilization throughout the crop cycle; M2: 75% mineral fertilization throughout the cycle + 25% organic fertilization (cattle manure) at bud break; M3: 75% mineral fertilization throughout the cycle + 25% organic fertilization (pig slurry) at bud break; M4: 50% mineral fertilization throughout the cycle + 25% organic fertilization (cattle manure) at bud break + 25% organic fertilization (pig slurry) at post-harvest.

The sampling of leaves and fruits and the N quantification was conducted according to standard methods.

Our results indicated that there are no statistical differences between treatments in terms of N content in leaves. Regarding the nitrogen content of the fruits, there was a clear trend towards higher N values in the control treatment, with the highest value measured being 1745.9 ±

192.343 mg N $kg^{-1}$ and the lowest value being 574.6 ± 50.641 mg N $kg^{-1}$ (values expressed on fresh weight). The minimum value obtained in this trial was clearly higher than that reported in the literature. It can be concluded that despite significant statistical differences in the N content of the fruits, none of the treatments induced lack of nitrogen.

**Acknowledgements:** This work is funded by the program IFAP/PRR/Agenda de investigação e inovação para a sustentabilidade da agricultura, alimentação e agroindústria, through the project MO PLUS (PRR-C05-i03-I-000018). And by national funds through FCT - Fundação para a Ciência e a Tecnologia, I.P., under the projects UIDB/04129/2020 of LEAF-Linking Landscape, Environment, Agriculture and Food, Research Unit and LA/P/0092/2020 of Associate Laboratory TERRA.

## Assessing the feasibility of using waste biorefinery in livestock farming systems

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### Abstract

The use of sustainable agricultural and bio-waste management systems is an important element of the circular economy. The concept of a waste biorefinery fits well into these postulates, promoting holistic technological solutions aimed at the recovery of biobased products and bioenergy (Chojnacka, 2023). Biorefineries can use simple techniques aimed at the production of fertilizers and/or energy, or more advanced ones enabling the production of a wide range of biochemicals, polymers, feed and food ingredients. Due to the complexity and diversity of biorefinery solutions, there is a need for scientifically justified quantitative data regarding the technical, economic and ecological aspects of biorefinery operation in various contexts, including livestock farming systems (Lindorfer et al., 2019). In order to showcase viable solutions, we collected detailed technical and economic data from a Polish livestock farm equipped with a bioreactor. A custom-made software tool helped to quantify product and waste streams (including energy) and their respective economic value. Under a variety of possible detailed use cases, different economic and ecological impacts of this farm were assessed and extrapolated to biorefineries of different sizes for the conditions of the Polish livestock sector.

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## Interactions between inoculation with arbuscular mycorrhizal fungi and fertilization with different organic products in Allium porro plants

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### Abstract

The use of organic fertilizers is emerging as paramount amidst the scarcity of mineral nutrients and fossil fuels needed to manufacture and transport inorganic fertilizers. The processing of livestock manure may improve its quality as a fertilizer. Additional crop nutritional benefits can be obtained through root inoculation with arbuscular mycorrhizal fungi (AMF). However, relatively few agronomical studies have been conducted on the combined application of different organic fertilizers and the inoculation of AMF. We studied the response of plants to the interaction between AMF inoculation and fertilization with 5 cow-manure based organic products submitted to different processes (anaerobic digestion, composting, bioacification). Leek seedlings (160) were used in a factorial (mycorrhizae*fertilizer) trial, in 1L containers with washed and autoclaved river sand. The mycorrhizal factor consisted of inoculation with Rhizoglomus irregulare and without AMF inoculation. The fertilizer factor comprised mineral fertilizer (with and without); cow manure once bioacidified, digested, a composted as mixture with olive oil mill wastes; and cow manure digestate and compost both enriched with dark septate endophytes (DSE; Cladosporium sp.). All fertilizers were applied at the beginning of cultivation (170 kg-N·ha-1). After 196 days of plant growth under greenhouse conditions, plant height, and aerial and root part biomass were measured. Also plant nutrient recovery was calculated.

Mycorrhized plants assimilated nutrients from all organic fertilizers more efficiently than non-mycorrhized plants and produced higher biomass yields ($p<0.05$). Among non-mycorrhized plants, those fertilized with digestate also resulted in significantly higher yields than plants supplied with compost (amendment).

## Nitrogen fluxes in Urochloa-based pasture soils in the northwestern Amazonia

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### Abstract

In the northern Caquetá department of Colombian Amazonia, pastures have been for more than 50 years managed unsustainably, resulting in rapid pasture degradation in terms of low forage productivity and loss of nutrients, especially nitrogen (N). In this study, we aimed to quantify the major soil N fluxes in farmers' pastures. On six farms in a transect of 90 km we measured soil mineral N, microbial biomass N (MBN), gross N fluxes, and gross C mineralization of pasture soils (0–10 cm) in a laboratory incubation (24 h). The pastures surveyed included 12 grass-alone (GA) and 12 grass-legume (GL) plots, the grass species being Urochloa humidicola, U. decumbens and U. brizantha, and the legumes Arachis pintoi and Desmodium ovalifolium. GA pasture soils had significantly higher MBN than GL soils (37 vs 29 mg N kg soil$^{-1}$), as well as a higher rate of gross C mineralization (41 vs 20 mg C kg soil$^{-1}$ day$^{-1}$) and lower N-$NO_3^-$ content (5.6 vs 27.5 mg N-$NO_3^-$ kg soil$^{-1}$). The gross N fluxes were not significantly affected by pasture composition. First results indicate that the largest fluxes were (on average for all pastures) gross ammonification (3.2 mg N-$NH_4^+$ kg soil$^{-1}$ day$^{-1}$), and gross $NH_4^+$ immobilization (3.0 mg N-$NH_4^+$ kg soil$^{-1}$ day$^{-1}$). Gross nitrification was on average 0.5 mg N-$NO_3^-$ kg soil$^{-1}$ day$^{-1}$, whereas gross $NO_3^-$ immobilization was negligible. Considering that gross nitrification was higher than net ammonification (0.2 mg N-$NH_4^+$ kg soil$^{-1}$ day$^{-1}$) and $NH_4^+$ immobilization was a significant flux, further research is needed to understand the effect of pasture composition on plant nutrition and soil N losses.

Monitoring temporal and spatial trends in $NO_2$ pollution in Sri Lanka

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## Abstract

This study was aimed to assess the trend in atmospheric $NO_2$ levels in Sri Lanka from 2011 to 2021 using satellite data. Sri Lanka experiencing two monsoon seasons, one winds originate from main land Asia and Bay of Bengal (North East Monsoon (NEM)) and one from winds originate in the southwest of the Indian Ocean (South West Monsoon (SWM)). Data was obtained from Geographical interactive online visualization and analysis infrastructure database of NASA. Daily records of time series, area averaged $NO_2$ measurements for tropospheric column (30% cloud screened) were collected at 0.25° resolution. Trend in monthly and annual averaged $NO_2$ levels were assessed for whole country, and montane (>900 m amsl) and low elevation region. Results revealed, no trend in mean annual $NO_2$ levels ($7.43 \times 10^{14}$ molecules $cm^{-2}$) for the period and the highest levels was recorded in 2021 ($7.85 \times 10^{14}$ molecules $cm^{-2}$) while 2017 had the lowest ($6.98 \times 10^{14}$ molecules $cm^{-2}$). The NEM had higher $NO_2$ level than SWM. The $NO_2$ level in NEM decreased from November to February, while increased in SWM from May to August. Montane region which expose to transboundary effects from Indian continent from both monsoons showed significantly higher $NO_2$ levels year-round. November had the highest $NO_2$ level in both montane and low country and the lowest in May) in montane region and June in low lands. Overall results revealed, transboundary effect is the main reason for the elevated $NO_2$ levels in NEM season, and in the montane regions in the country

Microbial mechanisms of nitrous oxide reduction in diversifying crop rotations

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## Abstract

Diverse crop rotations are increasingly recognized as key to tackling the global food crisis and enhancing environmental sustainability, including reducing nitrous oxide (N2O) emissions. However, the specific impact of various crops in these rotations, especially when combined with traditional crops, on N2O emissions and the underlying microbial processes remains underexplored. In a six-year study, we compared N2O emissions from traditional wheat-maize rotations with diverse rotations, including legumes (peanut, soybean), grass and cash crops (ryegrass and sorghum), and cash crops like sweet potato, examining the associated microbial processes by conducting functional predictions related to the nitrogen cycle. Our study showed that diversifying crop rotations with reduced fertilization and irrigation can decrease $N_2O$ emissions by 34% to 55% compared to conventional rotations. The reductions were further supported by the increase in soil organic carbon, particularly observed in rotations involving legumes and sweet potatoes. However, the ryegrass-sorghum rotation had the highest emission factors among all rotations, because of enhanced microbial biomass carbon boosting nitrification and denitrification. Additionally, changes in microbial community, including increased activity of ammonia-oxidizing bacteria MND1 and archaea Candidatus Nitrososphaera in legume and sweet potato rotations, and a shift in denitrifying microbes of diverse rotations (a decrease in Rhodoplanes and an increase in Paracoccus), significantly contributed to the overall reduction in emissions. Our study suggests that diversifying crop rotations offer a sustainable agricultural approach to managing N2O emissions. Understanding the microbial mechanisms driving N2O emissions enables the development of more effective strategies to reduce greenhouse gas emissions further.

## 2.4 Session 4: Incentives for good nitrogen management

## Water-nitrogen nexus for nitrogen-splitting in alternate wetting and drying rice; consequences for dry matter production, agronomic and economic performance

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### Abstract

Water and nutrients interact in harvesting potential crop yields in different rice production systems (Zhang et al., 2021). Various splits viz. two or three of recommended nitrogen (143 kg N ha$^{-1}$) were evaluated for crop growth, dry matter production, agronomic performance and profitability in alternate wetting and drying (AWD) in comparison to conventional flooded rice (TPR) for two growing seasons. Variable responses of N splits and years were found to crop growth and yield in rice systems. Three N splits with one-half at sowing, remaining half at tillering and anthesis produced maximum total dry matter and chlorophyll contents in AWD than TPR. Two splits with one-half each at basal and anthesis produced maximum leaf area index and duration, crop growth and net assimilation rates in AWD compared to TPR. Three equal N splits each applied at sowing, tillering and anthesis also produced maximum crop growth, highest total and fertile tillers, panicle length, straw and kernel yields in TPR than AWD. Three and two equal N splits showed the highest agronomic and yield components in AWD. Reduced kernel numbers, 1000-kerenl weight and less harvest index were the possible reasons for reduced yield under AWD (Zhang et al., 2021). Nonetheless, total N uptake, water productivity and benefit cost ratio were high under AWD for three or two N splits compared to TPR. Three N splits with one-half at sowing and remaining half at tillering and anthesis can be practiced safely under AWD conditions for high yield and reduced water inputs.

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## Impact of PET microplastics on nitrogen cycling and soil microbial activity

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### Abstract

Many studies demonstrate the negative impact of microplastics, small plastic particles contaminating the environment, on flora, fauna, human health, and soil quality [Qi, 2020]. Microplastics have been shown to significally affect soil properties (aggregation, water retention, activity of microorganism, stability and quality of soil organic matter and nutrients cycling) [Yu, 2022]. Nitrogen cycling in soils is key in the maintenance of nutrient (nitrogen) accumulation which is essential for amino acid and genetic material production in all living organisms [Jiang, 2023].

This research studies the effect of different sizes of PET microplastics on agricultural soil, enriched with urea-based fertilizer. In a short-term experiment (28 days), the changes in ammonia and nitrate nitrogen concentrations were monitored in two different soils contaminated with microplastics. To provide further information on the impacts of microplastics on soil fertility and the nitrogen cycle, these results were compared to soil respiration experiments.

The results demonstrate that microplastics have varied effects on soil properties. Soil respiration results indicate that the presence of microplastics in soils enriched with urea has an impact on soil microorganism functioning. Furthermore, results provide insight into the impact of microplastics on the cycling of nitrogen in these soils. It was observed that these changes will depend on the size of the microplastics and the soil type. The presence of microplastics in soils has the potential to affect the soil nitrogen cycle and soil fertility.

The work was supported by the project FCH-S-23-8297 of the Ministry of Education, Youth and Sports of the Czech Republic.

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## Reducing environmental impact and enhancing Agricultural Yield and Nitrogen Efficiency through Digital Climate Models and Field Acidification

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### Abstract

This study presents an innovative approach to improving agricultural yield and nitrogen efficiency using online digital climate models and field acidification techniques. The research focuses on the challenge of ammonia, N2O and CO2e emissions from slurry in agriculture in combination with use of mineral fertilizer. Utilizing the Alfam 2 ammonia emission model developed by Aarhus University integrated in a slurry tanker with field acidification, the study demonstrates a reduction in nitrogen loss through ammonia evaporation, avoiding N2O emission and nitrate leakage and improving the economy. The combination of field acidification, which converts ammonia to ammonium thus preventing evaporation, and the Alfam 2 digital climate model, enables optimized sulfuric acid use and management of mineral fertilizer dosage rate through identification of NPA (Nitrogen Plant Availability) for improved slurry nitrogen utilization. The results show significant improvements in yield potential and environmental impact, contributing to the reduction of N2O and CO2e emissions. Significantly, the research findings align with European Union directives aimed at enhancing environmental sustainability in agriculture and it is scalable in all of Europe. By adopting this method, farmers can achieve a dual objective: maximizing crop yield while minimizing adverse environmental impacts, notably in the realm of ammonia, N2O and CO2e emissions. This study is a step towards a more sustainable agricultural sector, offering a pragmatic yet innovative solution that bridges technological advancement and environmental stewardship.

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Sasha Hafner [a 1], Andreas Pacholski [b 2], Shabtai Bittman [c], William Burchill [d], Wim Bussink [e], Martin Chantigny [f], Marco Carozzi [g h], Sophie Génermont [h], Christoph Häni [i], Martin N. Hansen [j], Jan Huijsmans [k], Derek Hunt [c], Thomas Kupper [i], Gary Lanigan [d], Benjamin Loubet [h], Tom Misselbrook [l], John J. Meisinger [m], Albrecht Neftel [n], Tavs Nyord [o], Simon V. Pedersen [a]...Sven G. Sommer [a] 2017. The ALFAM2 database on ammonia emission from field-applied manure: Description and illustrative analysis

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M. Toft [*], C. T. Madsen, BioCover A/S, Veerst skovvej 6, 6600 Vejen Denmark. 2019 Experiences With 7 Years of Acidification in Denmark-SyreN System, a commercial method to fertilize with Sulphate while reducing animal slurry ammonia emission.

## Fertilization of vegetable cops according to EU directive in Germany

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### Abstract

The EU Commission has withdrawn infringement proceedings against Germany (DE) for non-compliance with the EU Nitrates Directive in June 2023. This was possible after Germany completely amended its fertilizer legislation (Fertilizer Act, Fertilizer Ordinance and Material Flow Balance Ordinance) in 2017 and 2020. The Fertilizer Ordinance (Düngeverordnung, DüV) is the action program of the EU nitrate directive and the amendment will be presented in the following. Vulnerable zones are designated on the whole German territory. The DüV clearly defines compulsory fertilizer planning for nitrogen and phosphorus with standardized target values for agricultural and vegetable crops. Regulations in vegetable crop production concern i.e. compulsory measuring soil mineral nitrogen, application of organic or organic-mineral fertilizers, fixed blocking periods for fertilizer application, threshold of 170 kg N $ha^{-1}$ $year^{-1}$ from animal and plant sources, non-receptive-soils, incooperation of liquid livestock manure, recording all fertilizer applications, preparation of a nutrient balance at the end of the year and others. The amended DüV obliged the federal states to designate hot spot areas with high nitrate or phosphorus pollution with increased requirements for nutrient management. Thus seven national regulations have to be adopted in all states (i.e. greening, reduction of originally calculated nitrogen demand by 20%, prolongation of blocking periods for nitrogen and phosphorus application) plus three additional measures. The federal states select the latter from a catalog with additional fertilization requirements.

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DüV, 2020. Verordnung zur Änderung der Düngeverordnung und anderer Vorschriften vom

28. April 2020 (bgbl120s0846.pdf)

# SCAIL Sweden - A tool for assessing local impacts of emissions from large livestock facilities

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## Abstract

In Sweden, permits are required for large livestock facilities (IED 2010/75/EU). Hence their potential impacts on the environment, including the impact of concentrations and deposition downwind of the installation, need to be assessed (Habitats Directive 92/43/EEC). However, simple, cost-effective operational tools to evaluate these environmental effects, are lacking in Sweden. For instance, Environmental Impact Assessments (EIAs) currently often assume that the dispersion of ammonia is extensive, with a very limited impact on the immediate area.

The assumption is often that half of the ammonia emission from the unit is spread evenly within the nearest 50 km from the source (Johansson and Albertsson, 1997). In fact, ammonia concentrations (and deposition) strongly decrease with distance from source (Theobald et al, 2009). Therefore, local effects of nitrogen emissions from intensive animal husbandry have been underestimated in Sweden, which reduces incentives and demands to implement efficient mitigation measures to reduce ammonia emissions from livestock units.

We have developed a web-based air dispersion tool, SCAIL Sweden, based on Theobald et al (2009), originally developed for the UK. The SCAIL tool focuses on assessing nitrogen load, acid deposition and ammonia concentration from large agricultural facilities in Sweden. The tool improves the assessment of environmental impacts in the permitting process, particularly for pig, poultry and cattle farms. SCAIL Sweden will support the county administrative boards to exercise their regulatory responsibilities and improve operational efficiencies. The tool has been developed together with stakeholders like farmers, planners, and regulators, ensuring a comprehensive and effective tool for the end-users.

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# Identifying economic optimum nitrogen rate for crops in Denmark

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## Abstract

In Denmark, the amount of nitrogen (N) fertilizer that farmers are allowed to use is stated by an N norm system, which is based on the economic optimum for specific crops and soil types.

For the major crops in Denmark, the N norms are derived from field experiments with increasing N application rates. Every year, a series of experiments is conducted in different crops. The long tradition of these experiments has resulted in more than 1000 N rate experiments in winter wheat since 1987.

As the N optimum varies from year to year, the norm is calculated based on experiments from the last ten years. This yields an N norm that is relatively stable, minimizing yearly fluctuations. Information about factors that have an N residual effect in the following years is collected from the fields where the N experiments are carried out. This includes crop rotation, application of animal manure, and use of cover crops. The information is highly detailed for the past five years and used in the calculation of the economic optimum.

To calculate the economically optimal N level, prices of fertilizer and crops from the past five years are included. The relationship between the prices of N and crops changes from year to year, directly affecting the N norms. For example, the increase in fertilizer prices in 2022- 2023 will result in lower N norms in the coming years.

The system provides a solid base for optimum N application rates in Danish fields.

# Effect of organic manures on hybrid and open pollinated cultivars of cauliflower in Nepal

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## Abstract

Cauliflower, an important commercial vegetable crop grown in terai and mid hills of Nepal, ranked first in terms of area (39,214 ha), production (611,015 t) and productivity of 15.58 t/ha (MOALD, 2022). Majority of the farmers grow different Open Pollinated (OP) and hybrid cauliflower cultivars in mid-season because of favorable environmental condition, low cost of production and higher yield as compared to early and late season but the national productivity is least compared to globe thus to boost the production farmers are using high external chemical nitrogenous fertilizer which continually depleting the soil productivity. Thus, this study was conducted at Tulsipur, Dang, Nepal during 2023 A.D. to assess the yield performance of four cauliflower cultivars i.e. 2 OP (Khumal Jyapu and Agheni) and 2 hybrid (Super White Top and Snow Crown) supplied with four nitrogen sources (100% from farm yard manure, 100% from poultry manure, 100% from vermi-compost and government recommended fertilizer dose i.e. 30 t FYM and 200:120:80 NPK kg/ha. The experiment was laid out in split plot design with four nitrogen sources as main plot factor and four cultivars as sub plot factor with a total of 16 treatments and replicated four times. Considering the economically important growth and yield attributes, Khuma Jyapu (22.35 t/ha) and Super White Top (28.21 t/ha) supplied with 100% nitrogen sources from poultry manure significantly showed the highest yield and are recommended as best OP and hybrid cauliflower cultivars respectively in mid hills conditions of Nepal.

Keywords: Cauliflower, open pollinated, hybrid

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## Nature-based solutions for circular nutrient flows at regional scale - development of a decision support tool for farmers, advisors and policy makers

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### Abstract

The implementation of more nature-based solutions (NbS) in agriculture has the potential to improve ecosystem functions of landscapes while enhancing resilience in agricultural food production (Simelton et al. 2021, Iseman and Miralles-Wilhelm, 2021). Their adaptation requires collaborative efforts between farmers as well as with the bioindustry for which there is only limited information available to guide decisions. Within the trans4num.eu project, we aim to develop a dynamic, smart nutrient management decision support tool (DST) to foster this transformation.

Nutrient management tools for fertilization planning or record keeping at farm and field levels are widely available. However, landscape level research and DSTs that integrate over several farms and support collaborative efforts in optimizing nutrient flows are lacking. Our novel DST will tackle this research gap as it considers several spatial and temporal scales beyond the single farm level while making use of the outputs generated by farm level tools. It will include satellite-based remote sensing information on crop area and biomass productivity. A first prototype will be developed for a case study in the Limfjord region, Denmark. Here, a reduction in excessive nitrate loads to the fjord is aimed for by converting arable crop rotations towards more permanent or rotational grassland and using the biomass for biorefinery purposes. In the future, the tool will also be adapted to case study sites in Hungary, the Netherlands and the UK where different NbS focusing on circular nutrient flows are currently tested. At the N workshop, we will present the conceptual design of the DST together with its intended use in the Limfjord region.

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## Identifying barriers for improving nutrient management at Danish farms

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### Abstract

We conducted a survey amongst farmers, advisors, scientists, and agricultural sales representatives to improve the understanding of farmers motivation for better nutrient management and to identify the barriers for implementation of better nutrient management at Danish farms.

In total we received 47 responses from farmers, 11 from scientists, 10 from advisors and 13 from sales representatives. In the survey we asked about nutrient management planning, tools and technologies and the needs of farmers and the experienced barriers.

The farmers were motivated by better yields and improved economic returns to improve their fertilization practices. About half of the farmers also replied that reducing nutrient losses to the environment were a motivating factor as well. Among scientists, advisors and sales representatives, yield level and economic ranked highest, and reduction of nutrient losses ranked the lowest. When asked what the primary challenges for farmers to implement new tools and technologies, the farmers asked lack of fonds to invest and that the cost of new tools and technologies are too high. The agricultural advisors and scientists pointed out that there is a need for more user-friendly tools, improved knowledge about the availability of nutrient in specific fields and a larger sharing of new knowledge. There was a large agreement across the responders that in order to improve the fertilization practices in the future, better use of satellite-based models and integration of soil and plants samples in the fertilization planning before and in-season is highly needed.

Nitrogen leaching measured with suction cups in 12 maize field trials

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## Abstract

In 2019-2022, 12 field trials were conducted to measure N leaching from maize. Leaching was monitored using suction cups from June to April the following year.

The effects of different strategies for catch crops and strategies for slurry application have been examined for leaching and maize yield. In the first year after plowing of clover grass the additional leaching is 40 kg N/ha compared to 5 years or more after clover grass.

If maize is grown 1-3 years after clover grass the effect on a higher yield is small, whereas after more than 4 years since clover grass, there is a higher effect on the yield. The supply of nitrogen should be reduced in several years after ploughing of clover grass.

Catch crops with a large coverage can reduce the leaching with up to 50-70 kg N/ha compared to catch crops with a minimal coverage, and there is a clear connection between coverage and leaching. But large catch crops can also affect the maize yield negatively.

In trials where the slurry has been placed at the time of maize sowing, the crops have taken up 20 kg N more than trials where the slurry has been injected, but the leaching is higher where the slurry has been placed compared to injected slurry. This might be because it is hard to use suction cups to measure leaching in these sorts of trials where the variation is not taken into account, because N-min measurements show lower leaching with placed compared to injected slurry.

# Nitrogen footprint optimization in extensive grazing systems following sludge application

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## Abstract

Effective nitrogen (N) management in agricultural systems is crucial for minimizing N losses with related environmental impacts and maximizing productivity. This study evaluates the impact of sludge application on an extensive grazing system in Portugal, using an integrated approach that combines soil and sludge analysis with advanced remote sensing data (NDVI-R, Colour, NDRE, Thermal, and PCD). The objective was to correlate the dynamics of the nitrogen cycle, as evidenced by variations in NDVI-R, Colour, NDRE, Thermal, and PCD changes in soil analysis, and precipitation patterns, with sludge applications to assess nitrogen use efficiency and the resultant nitrogen footprint. Soil analysis conducted before, during, and after sludge application provided data on available nitrogen forms (ammoniacal and nitrate), while sludge analyses helped characterize the potential nitrogen contribution. The integration of these data with remote sensing indicators—reflectance measures indicating vegetation health and productivity—and precipitation data facilitated a precise assessment of pasture response to nitrogen management under varying weather conditions. Preliminary findings indicate significant alterations in the nitrogen cycle within the system following sludge application, with direct implications for the nitrogen footprint. Correlation between remote sensing data, soil and sludge analysis, and meteorological records suggests that remote sensing technologies, particularly the analysis of Sentinel-2 satellite imagery, could be invaluable tools in optimizing fertilization strategies and reducing nitrogen losses through leaching and volatilization. Moreover, this comprehensive approach has enabled the identification of management practices that enhance carbon sequestration and soil quality, contributing to the more sustainable management of extensive grazing systems under the influence of precipitation variability.

## Aknowledgements

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SmartField – Science policy practice

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## Abstract

The agricultural sector, which contribute nearly one-third of all greenhouse gas (GHG) emissions in Denmark is under increasing pressure to achieve 55-65% reduction in the coming years. While current GHG calculations for this sector follow the IPCC's Tier 1 and 2 methodologies, national reporting of soil nitrous oxide (N2O) emissions to the UNFCCC advances towards data driven approaches using either a Tier 2 or 3 methodology, the latter being the preferred.

The Danish initiative, SmartField, aims to establish an innovative field-scale platform for testing and validating measures to reduce N2O emissions from agricultural fields.

The core activities include: 1) establishing a field measurement infrastructure to provide state-of-the-art benchmark datasets of N2O fluxes and other N loss pathways for field management practices; 2) a data assimilation and modeling hub for evidence-based models for N2O emission quantification; and 3) a science policy practice forum to exchange knowledge and provide evidence-based tools for decision-making at field, farm, and national scale.

SmartField is initiated in Q2, 2024 and runs for min. 5 years. The initiative is led by the Danish Technological Institute in collaboration with Aarhus University, the University of Copenhagen, Colorado State University, SEGES Innovation, and the Danish Ministry of Food, Agriculture and Fisheries. The overall objective is to establish an internationally unique research and test platform, whereby Denmark can provide a showcase for accurate accounting of N2O emissions, testing, and implementing mitigation measures. The activities and prospects within SmartField to accomplish the overall objective and how SmartField can be incorporated into international initiatives and networks will be presented.

## 2.5 Session 5: Food systems

WORK SHOP
2024 AARHUS

# Does field irrigation fail to ensure food production? Review from hydrologic- human perspective

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## Abstract

I reviewed field irrigation as integral of both physical and human sciences to reveal an outdated mechanical link between irrigation and aridity postulated decades ago. Main aim of field irrigation is to provide the basis of society through resource collectivism and to enhance security of its people through consistent food supply, whereas crop yield and drought are secondary economic vectors of irrigation uptake. Therefore, local socio-economic and biophysical contexts must, but not always, meet when designing and operating field irrigation. Despite success stories, recent retrospective studies from Sub-Saharan Africa (Bjornlund et al. 2022, 2020) and Central America (Montero-Mora and Dermott 2023) show undermined local ecosystem services and specialized export-oriented productive spaces of irrigated crops unfit to local context. Moreover, amid plethora of Information and Communication Technologies, most farmers in all countries practice non-scientific decision on when and where to irrigate. Scheduling thus remains top priority task as both too little and too much water leads to yield decreases and loss of nutrients. The link between canopy spectral reflectance and surface energy balance, alongside data recorded at high resolution, allows to precisely estimate crop transpiration (beneficial water consumption) and soil evaporation (non-beneficial water loss), and schedule field irrigation. This opportunity is dammed by digital gap between technology developers and farmers as irrigation end-users, repeatedly emphasizing lack of human attention to irrigation as social technology. The review concludes with an urgent need for macro-level drought governance in order to strengthen multi-sectoral water management and mitigate weather-induced damages to human and natural assets.

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How do diet shifts affect the greenhouse gas balance of agricultural soils? Denmark as a case study

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## Abstract

Current food systems account for approximately 30% of anthropogenic greenhouse gas (GHG) emissions, and therefore, consumers' dietary preferences can have strong consequences for the environment. This is well known for the GHG mitigation achieved by reducing animal protein consumption and associated methane emissions. However, the effects of diet shifts for the soil GHG balance have not been comprehensively evaluated yet. In this study, we employed a two- sided approach to investigate the impact of dietary changes following the EAT-Lancet diet guidelines on GHG emissions from agricultural soils. Firstly, we used the outputs of the economic general equilibrium model MAGNET to quantify the demand-driven changes in food consumption at the national level for the European Union (EU) under a diet shift scenario. We then employed the DayCent biogeochemical process-based model to assess the implications for the GHG balance of agricultural soils at a regional scale, with Denmark as a case study. Our findings indicate that, compared to business-as-usual diets, the adoption of the EAT-Lancet reference diet would cause agricultural soils to experience significant carbon loss (up to 15 Mg of CO2e $ha^{-1}$), and a potential increase in direct N2O emissions by 5.8% (141.9 Gg CO2e $y^{-1}$), from 2030 to 2100. These changes primarily stem from the reduction in animal manure application to soil and a decrease in the share of permanent grasslands. The soil GHG balance differed largely across pedo-climatic conditions. These findings underscore the challenges faced by policies aiming to create healthier food environments, which need to be aligned with efforts to reduce anthropogenic GHG emissions and protect agricultural soils.

# Global food intake data suggest protein is more relevant than calorie in assessing feeding capacity

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## Abstract

Both proteins and calories are indispensable nutrients in diets and are both widely used as food supply indicators (FAOSTAT, 2023). Calories express the energy value of food and proteins its content in amino-acids which are involved in multiple metabolic functions. For both calories and proteins there are specific metabolic requirements that guide health recommendations of minimum and maximum intake. Here, we examine the relative intake of calories and proteins over time and across countries from FAOSTAT data and spotlight an insightful trend: no country demonstrates an overconsumption of proteins without a simultaneous overconsumption of calories. High-income countries overconsume both proteins and calories, low-income countries experience under-consumption of both nutrients and middle-income countries show calories overconsumption and proteins under- consumption. This stark disparity and, in particular the absence of relative shortage of calories compared to proteins in food supply, underscores the intricate relationship between the two nutrients and emphasizes that a sufficient protein supply also implies a sufficient caloric supply. This observation holds true over time and for all countries since 1961. The findings suggest that focusing on proteins rather than calories in agri-food system modeling allows for a more comprehensive and accurate assessment of feeding capacity (Chatzimpiros and Harchaoui, 2023). In addition, protein-based assessments also allow directly linking feeding capacity with environmental sustainability in terms of nitrogen cycling. While we show the higher relevance of proteins compared to calories in assessing feeding capacity, the joint use of proteins and calories is meaningful for integrating food and energy challenges in agricultural modelling.

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## Response of sixteen cassava (Manihot esculenta Crantz) cultivars to nitrogen fertilizer in Southwest Nigeria

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### Abstract

Fertilizer nitrogen (N) application is important to sustain yields; with too much application resulting in leaching from farmlands through surface runoff and water pollution. Cassava (Manihot esculenta Crantz) is a very important root crop and the second most important crop after maize in sub-Saharan Africa (SSA), where it is grown for food by smallholder farmers with Nigeria and Democratic Republic of Congo being the largest consumers. N is the major limiting factor for cassava yield, and thus higher quantity of N fertilizer may be applied to obtain high yields. Cassava cultivars respond differently to fertilizer application, notwithstanding, yield could be increased with improved genotypes and fertilizer N application. Two years field trails were conducted between 2019 and 2020 in the transition rain forest of southwest Nigeria on a well-drained sandy soil. A split-plot design was used for field trial, with two N rates (0 and 100 kg/ha) and 16 cassava cultivars as main and sub-plots respectively. The sixteen cultivars responded differently to N fertilizer application in their root weight, root number, shoot weight and biomass weight. There was a strong positive correlation between the number of roots and shoot weight. N had positive influence on root weight but their effects are not statistically significant.

Keywords: Cassava, nitrogen, cultivars, root yield, sub-Saharan Africa

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Regional biophysical impacts of land use and land cover change over West Africa: A systematic review

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## Abstract

Anthropogenic Land Cover Change (LCC) impacts the regional water and nitrogen uses, and model-based coupling with surface meteorology and hydrology is a powerful tool to study LCC effects. The main aim of this work was to review the state-of-knowledge for the biophysical impact of LCC on regional surface climate, draw quantitative relationships between surface climate and land surface characteristics, and discuss critical challenges in LCC-climate studies. The rest region was West Africa and the Preferred Reporting Items for Systematic Reviews and Meta-Analysis method was used for in-depth focus on 29 out of nearly 6000 (n=5986) studies sourced from databases (Web of Science, Scopus, Google Scholar, WASCAL).

The results revealed direction, magnitude, and uncertainty of spatial temperature and precipitation response to LCC biophysical effects, depending mainly on model structure and LCC scenarios. Across all time periods, deforestation and LCC introducing agriculture and impervious surfaces (urbanisation, infrastructure) consistently led to increased surface temperature (2.5°C) and albedo (24%), accompanied by decreased precipitation (-0.9 mm/day) and leaf area index (-3.9 $m^2/m^2$). In contrast, afforestation/reforestation tended to enhance precipitation (1.7 mm/day) and LAI (3.2 $m^2/m^2$), while reducing surface temperatures (-1.8°C) and surface albedo (-40%). More recent studies and those using regional climate show warmer and drier results under future deforestation, indicating a potential underestimation of climate disadvantages for deforestation, and the opposite for reforestation. These findings suggest land restoration through biophysical activities involving reforestation as the most effective approach to improve regional climate conditions in West Africa.

**Keywords:** land-cover change, deforestation, afforestation, reforestation, regional climate, modeling, mitigation.

## Growth and root-shoot yield of Amaranthus cruentus as influenced by urine-water dilutions

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### Abstract

Amaranthus cruentus is a nutritious vegetable whose agronomic performance is enhanced by nitrogenous fertilizer application (Kunene et al., 2019). Meanwhile, some wastes (including human urine) that are sources of environmental pollution can be potential sources of cheap nitrogenous fertilizer for Amaranth production if recycled (Simba et al., 2020). This research therefore evaluated the response of Amaranthus cruentus to NPK (15:15:15), 1:2, 1:4, 1:6 urine-water dilution (UWD) applied at 100 Kg N/ ha (AdeOluwa and AyanfeOluwa, 2015) and no nutrient additive as check. At 3 and 4 weeks after sowing (WAS), data were collected on growth parameters (plant height, stem girth and number of leaves) while data on yield components were collected at 4 WAS. The result showed that Amaranth in NPK treated soil had highest plant height (62.66 cm) and stem girth (2.71 cm) at 4 WAS, which compared statistically with 1:2 UWD treatment. The maximum number of leaves at 4 WAS (16.63) was obtained from 1:6 UWD treatment and differed significantly from other treatments except NPK and 1:4 UWD. Meanwhile, 1:4 UWD gave the best weight for fresh and dry edible part with values significantly at par with NPK fertilizer; and 1:6 UWD (for dry weight only). Notably, the highest percentage of root in whole plant (13.14%) was recorded from control followed by NPK (7.76%). This study revealed that the UWDs influenced growth of Amaranthus cruentus positively and resulted to more assimilate partitioning to the edible parts. Howbeit, 1:4 UWD is recommended because of its production of highest edible part and could be adopted as nitrogenous fertilizer for Amaranthus cruentus cultivation.

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## Scaling up Sustainable Nitrogen Management along Global Agrifood Systems

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### Abstract

The growing demand for food, feed, fuel and fiber has led to significant increases in nitrogen

(N) consumption. Of particular concern is the demand for N fertilizer, which increased nine-fold in the last decades. This excess use of N has contributed to the triple environmental crisis: climate change, pollution and biodiversity loss. Ammonia emissions are contributing to air pollution, nitrate loads in water bodies are causing eutrophication and harming aquatic ecosystems and biodiversity, and nitrous oxide emissions exacerbate climate change. Conversely, many low-income countries face challenges in accessing N inputs, leading to soil health degradation and low crop yields. Urgent action is needed to address these issues and improve N use efficiency (NUE) while reducing N emissions and N waste across global agrifood systems.

Farmers worldwide are taking measures to improve NUE in agricultural systems. These efforts include adopting agroecological practices and bioeconomy approaches, such as best practices for fertilizer and manure application, enhancing soil health, closing crop yield gaps, boosting grassland and livestock productivity, optimizing dietary protein, and improving waste management and valorization. There is a call for policy support to scale up sustainable N management at global level in line with the 2030 Agenda for Sustainable Development, the Paris Agreement and Kunming-Montreal Biodiversity Framework. This paper addresses N challenges and opportunities in the agrifood system, and provides farmers, policy makers and other stakeholders with improvement pathways to increase NUE on farm and throughout the food production chain, and decrease nitrogen pollution from agrifood systems.

## Silicon fertilizers enhanced potato performance while reducing $N_2O$ emissions during drought at field scale

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### Abstract

Potatoes, with their small, shallow roots, are one of the most drought sensitive crops. The frequent increase in droughts caused by climate change has led to a significant decline in potato yields. Silicon (Si) fertilizer has the potential to increase the drought tolerance of potatoes while reducing N2O emissions through its influence on soil and plant properties. Therefore, we conducted a field experiment to determine the effect of Si fertilizer on potato production, soil/plant nutrients and N2O emissions under drought stress. The experiment was conducted on two soils of different texture (Orthic haplohumod-sand and Typic agrudalf-clay) with soil moisture (M) as the main plot (Controlled rainfall-CR and Drought-DT) and fertilizers (F) as split plots (Amorphous Silica-ASi and no Si control). Biomass samples were taken at tuber initiation, bulking and maturity and soil N2O emissions were measured using manual and automated closed chamber approaches. Based on the results, the effects of F on tuber yield followed a similar trend in both soils with sig. ($p<0.05$) higher overall tuber yields observed in ASi (40 t $ha^{-1}$) compared to control (30 t $ha^{-1}$) at maturity. Leaf phosphorous (P) content was sig. ($p<0.05$) higher in ASi (3.0 mg/100 g) compared to control (2.8 mg/100 g) in sand at bulking. Regarding soil N2O emissions, ASi had lower overall cumulative emissions compared to the control in both soils. Our results indicate that Si fertilization has the potential to be a sustainable solution for maintaining potato production while reducing N2O emissions under drought conditions.

## Nitrogen fertilisation and saline conditions affect the growth and sensory profile of rocket (Eruca sativa Mill.) and ice plant (Mesembryanthemum crystallinum L.)

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### Abstract

Nitrogen (N) is vital for plant growth, while salinity (SA) can decrease agronomical performance. Excessive N fertilization under saline conditions can increase salt accumulation in the root zone, impairing plant growth and enhancing SA effects. Although halophytic (salt-tolerant) crops exist, their success as a food product depend on factors such as yield performance and consumer acceptance. Rocket is a baby-leaf green expected to be salt-tolerant and known for its unique sensory attributes. Common ice plant is an edible halophyte, with a soft texture and "fresh" and salty taste. Our aim was to document the two species response to increasing N and SA levels in terms of yield and perceived sensory characteristics. Full-N (100 kgN/ha) and Half-N (50kgN/ha) treatments were evaluated in a randomized pot trial in a greenhouse. The plants were grown in sandy-soil under organic farming conditions, and irrigation water was used to apply four different salt levels (SA-0 to SA-12 mS/cm NaCl). The yields of both species were N and SA dependable, with an observed decrease in yield in response to HN treatments. Rocket yield showed a parabolic response to SA, with mid-range applications of NaCl (SA-4; SA-8) resulting in higher biomass compared to lower (SA-0) and higher (SA-12) levels, regardless of the N treatments. Ice plant presented higher biomass in response to all SA treatments compared to SA-0, but for this species, nitrogen appeared to be the yield limiting factor. Salinity had a significant impact on sensory profiles for both plants, while nitrogen had a minor effect.

## Evaluating decision making systems for N fertilizer applications under a variable climate

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### Abstract

Grain yield in Australia is frequently limited by N supply, and field level N mass balance is typically negative. Chronic under-fertilization stems from lack of government subsidy on production or fertilizer, and annually variable (tenfold) rainfall causing highly variable yields. Growers cannot accurately predict likely yield when deciding fertilizer rates, and fearing financial loss are conservative and rely on mineralization from soil organic matter to meet crop N demand. This causes a substantial yield gap and decline in soil organic matter (SOM).

N applied in farmer's fields is influenced by the decision-making processes that they use, and relatively few farmers use formal decision-making systems. We evaluated different decision-making systems in a 6-year field experiment for their ability to profitably close yield gaps and reduce mining of SOM. We compared a seasonally responsive decision-making system that predicts yield probabilities (Yield Prophet®, a commercial web-interface for APSIM – Holzworth et al. 2014) with a seasonally un-responsive system that maintains a predetermined level of N fertility (N banks – Meier et al. 2021).

Relative to the national average N rate of 45 kg/ha, best treatments of both systems applied more N (4 to 49 kg/ha/year), had a smaller exploitable yield gap (0 vs 8%), were more profitable (55-135 $AUD/ha/year) and maintained a neutral to small positive N balance (4 to 93 vs -39 kg/ha). These results demonstrate the clear benefits of using formal decision-making processes for determining N rate in a variable climate, and factors that prevent farmers from using such systems require examination.

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## Agricultural trade and the trajectories of countries in the safe and just operating space of nitrogen (1961-2021)

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### Abstract

Food production is the main human activity responsible for trespassing the nitrogen (N) planetary boundary. Trade of agricultural commodities can reduce food deficits, but it can also sustain over-consumption patterns, related to waste and to excessive meat and overall food intake. In this work, we address how production-related N impacts leading to planetary boundary exceedance (trespassing the critical threshold) are related to the just distribution of protein consumption (delimited by under or over consumption), thus defining a safe and just operating space of N. We combine agricultural N balances with bilateral trade datasets to trace N impacts along food chains and to map the trajectories of countries within and beyond this operating space. The preliminary results indicate that total N inputs and N inputs above critical threshold have increased by 150% and 330%, respectively, and the latter now represent half of total N inputs. The share of population living in countries under undernourishment risk has decreased from 62% to 12%, while the share in over-nourished countries has increased from 22% to 47%. Countries have generally moved towards boundary exceedance and over-nourishment, but many exceptions are observed. About 40% of the N inputs are used to produce traded commodities, and 80% of these commodities are imported by over-nourished countries, which source over 40% of these imports from countries with undernourishment risk and with increasing N exceedance. These results show to what extent the trade related to meeting over- consumption patterns is causing social and environmental impacts in producing regions.

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## Nitrogen Challenges and Perspectives from India - Air Pollution and Agri-food Systems

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### Abstract

India holds the 2nd largest agricultural land in the world, with 20 agro-climatic regions and nearly 157.35 million hectares of land under cultivation. Agriculture contributed 18% to the nation's gross domestic product (GDP) in 2023, with 55% of the population depending on agricultural activities for their livelihood.

The Indian green revolution in 1960s led to food security in India through adapted measures, viz., increased acreage under farming, adoption of high yielding varieties, increased use of inorganic fertilizers and pesticides, improved irrigation facilities, and improved farm implements[1]. However, the current agrifood sector is impacted by 2nd generational challenges of the green revolution. With significant increase in crop yields in the last 6 decades, the consumption of N-fertilizer in India has been growing rapidly, resulting in over- or imbalanced use of fertilizers, thus having dual burden of poor resource efficiency and environmentally adverse outcomes from the agriculture sector. Increased downstream losses of N has resulted in adverse environmental externalities, including soil health deterioration, reduced crop responsiveness to applied fertilizers, increased GHG emissions, poor air quality, thus threatening the quality of air, soils, and fresh waters, and thereby endangering climate-stability, ecosystems, and human-health.

This has necessitated focus on improving soil health for sustaining agrifood systems, as well as to reduce emissions from the agriculture sector, particularly from the fertilizer and manure usage.

The abstract aims to present some of the key Nitrogen challenges in agrifood sector that require attention and explore innovative measures that are viable for Indian context and landscape.

Reference examples (arranged first alphabetically and then further sorted chronologically if necessary):

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WORK SHOP
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## 2.6 Session 6: Livestock in agricultural systems from a nitrogen perspective

# Mineral substrates increase the risk of nitrate leaching in hen yards

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## Abstract

As chicken prefer to stay in vicinity of the stable, (Mirabito & Lubac, 2001) this area rapidly deteriorates as vegetation is lost and puddles form after rainfalls, causing muddy feet, dirty eggs and a hygienic risk. That is why the area is often paved or provided with substrates such as gravel, sand or wood chips. However, as a result of the hens' preference, the barn's vicinity is where most of the feces and nutrients accumulate (Wiedemann et al., 2018). To find out more about absorbing capacities of different substrates, bare soil, sand, types of differently sized gravel and wood chips were filled into wooden frames. To simulate the N- excretion of 3.000 hens in 0-5 m distance from the barn, realistic quantities of chicken feces were applied during the leaching period over winter (in total 555 g N/m²). The soil beneath the substrates was sampled every 6 weeks at 0-60 cm depth and its content of mineral nitrogen was analyzed. The results show that the amount of mineral nitrogen beneath the gravel (irrespective of its size) and sand increased continuously reaching an amount of 50 to 60 g $N_{min}$/m² (=500-600 kg/ha) thus indicating a high risk of nitrogen leaching. $N_{min}$-contents beneath wood chips remained below 20 g/m². Gravel mixed with feces increases risk of infection as it can neither be cleaned nor sanitized and is -unlike organic materials- unsuited as fertilizer. Furthermore, it is classified as contaminated waste by the German waste industry which entails (costly) professional processing before its disposal.

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# Influences of udder and metabolic health on the milk urea content of dairy cows

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## Abstract

To improve estimations of ammonia emissions of dairy cows it is necessary to follow the flow of Nitrogen. Because of the challenges of measuring protein intake from dairy herds there is a need of indicators which are easy to access.

Milk urea content is used to evaluate protein alimentation in dairy cows and its measurement is part of milk recording. It is positively correlated to the urinary nitrogen excretions (Burgos et al, 2010) which are the main cause of ammonia emissions.

As influences of health status on the milk urea content of the cow may occur, this factor has to be investigated in its effect if milk urea is to be used in estimation equations.

Five independent datasets were available and analyzed.

The first dataset included more than 6 million representative milk control data from the year 2015 from Germany and Luxemburg. Datasets 2 and 3 were generated during the BLE-projects "optiKuh"(2014-2017) and "eMissionCow"(2017-2023) and combined feeding tests of 12 research stations in Germany with recordings of daily individual feed intake and milk analysis. Datasets 4 and 5 are also milk recording data from the laboratories of the counties Mecklenburg-Western Pomerania (2020-2023) and Thuringia (2019-2020), each around

400.000 data. Datasets 4 and 5 included additional information about the differential somatic cell count and mastitis diagnosis.

In all 5 datasets, the milk urea content was significantly influenced by udder diseases. The significant effect of metabolic disorders on the milk urea content was not equal in all datasets.

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## Assessing nitrogen cycling on dairy farms in the Netherlands: trade-offs and synergies

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### Abstract

In the Netherlands, dairy farming has a high level of intensification with high nitrogen (N) inputs and losses to the environment, which is threatening biodiversity and water quality in most sensitive natural areas. A transition towards more circularity in agriculture might be a promising pathway to reduce environmental impacts and improve resource use efficiency. However, understanding the relation between sufficient productivity, low environmental impact, and nutrient cycling is key for development of successful circular food systems.

In this study we first assessed the current status of N cycling (i.e. through re-use of manure) in Dutch Dairy farms. Data was used for the years 2006 – 2022, with a total of 284 unique year and farm combinations.

Among the dairy farms investigated the nutrient cycling indicator CyCt showed that an input of N (e.g. synthetic fertilizer, imported feed) did never cycles once through the system, and on average only half a time. While the indicator UseCt showed that an input of N is always used once by a cow, and on average 1.3 times. Nitrogen use efficiency, represented by O/I, varied widely, between 0.29 and 0.47. We found that increased N cycling was related most to management with lower external N inputs, both from fertiliser and feed.

Furthermore, evaluation of intensive and extensive farms (respectively average of 29,400 and 12,961 kg milk/ha, and total system N input of 589 and 233 kg/ha) revealed a synergy between N cycling and greenhouse gas emissions, but at the costs of agricultural land use and productivity.

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## Coupling a cropping system model and a manure redistribution optimisation tool: a case study

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### Abstract

An integrated system was developed to support stakeholders in the identification of viable solutions to maintain crop productivity and reduce environmental impact at a local or regional scale. A software tool was designed to assess the opportunity of moving manure from farms with excess manure (surplus-farms) to farms where manure is lacking (deficit-farms) according to the crop N requirements. The tool ran at a regional scale, and it was applied in two case studies (Lombardy-Italy, Mors-Denmark), for which data deriving from regional N use database were available. The opportunity of manure moving was estimated with the integration of optimization algorithms that consider the distance between surplus-farms and deficit-farms, the costs and $CO_2$ emissions associated with manure transport and mineral fertilizers purchase in the deficit-farms. The outcome of the tool is the list of deficit-farms that take the advantage, in terms of costs and $CO_2$ emissions, of receiving manure and reducing the purchase and application of mineral fertilizer. In these farms, the ARMOSA model (Perego et al., 2013) was applied to quantify yield, soil organic carbon stock, crop N recovery, and N losses ($NO_3$ leaching, $N_2O$, $NH_3$ emissions) before and after receiving manure. Additional assessments were performed in deficit-farms after manure redistribution, to evaluate the environmental benefits of alternative management practices aimed at reducing N losses.

This system allows for a priori evaluation of the impact of manure movement on N use efficiency and soil carbon stock evolution across a wide range of pedoclimatic conditions and cropping systems.

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Perego, A. et al., 2013. The ARMOSA simulation crop model: overall features, calibration and validation results. Ital. J. Agrometeorol. 3, 23–38.

## Exploring landscape sustainability of an alternative beef production system – a geo- spatial approach to assess multiple benefits for society and nature

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Agroecology

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### Abstract

The ongoing intensification of agricultural production increase pressures on biodiversity, environment, and climate, and calls for re-thinking of agricultural production systems and landscapes. Often, research studies are dominated by a focus on single factor impacts on e.g. climate or nitrogen mitigation, while approaches embracing multiple aspects of agricultural impacts are neglected.

This study shows a new method to assess multiple benefits for an alternative beef production system, with a mixed structure (combination of grassing, agroforestry with energy crop production, and harvest of green biomass harvest for biorefinery fiber and fodder production). A geo-spatial method to select best-suited cereal fields to replace with the defined alternative beef-steer production system was used to assess multiple benefits based on five spatial- varying indicators, representing benefits for biodiversity, environment (reduced N loads), climate (reduced greenhouse gas emissions), for the farmer, and policy-implementation

The effects from the inclusion of one or multiple indicators in the assessment were in each case evaluated, by appointing the best suitable fields until the resulting area to get the present Danish consumption of beef from current intensive steer production was achieved. Results showed, that when aiming at multiple benefits (indicator factors >3) the selected land area decreases, and thereby also the related benefits at a national scale. However, significant benefits on a local scale still occurs. As a result, the method can be used as a decision support tool, exploring benefits and tradeoffs within specific societal areas of interest.

# Biomass yield and nutrient removal from outdoor pig systems when harvesting willow and poplar as green biomass for feed

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## Abstract

Trees grown in outdoor pig production systems may provide shade for the pigs, green biomass as a potential feed source as well as remove nutrients from the paddocks and, hence, reduce the risk of nutrient loss.

We performed two field trials in 2021-2022 in willow cultivar Tordis and poplar cultivar OP42, both with previous harvest during the winter 2020/2021. Green biomass including shoots and leaves was either harvested 24th June or 24th September 2021. Biomass yield and removal of N and P with harvested biomass was measured. In the willow trial, regrowth was harvested 22nd November 2022 and compared to no harvest in 2021.

Dry matter (DM) yield increased significantly from June to September, from 0.9 to 8.5 ton ha$^{-1}$ in willow and from 1.1 to 6.0 ton ha$^{-1}$ in poplar. N removal increased significantly from 32 to 114 kg ha$^{-1}$ in willow and from 24 to 56 kg ha$^{-1}$ in poplar. However, the content of crude protein decreased significantly from June to September, from 17.9 to 7.9% in DM in willow and from 13.6 to 5.25% in poplar, indicating a trade-off between yield and feed quality.

Total DM yield of willow over the years 2021-2022 was significantly reduced from 12.0 to

6.1 or 7.2 ton ha$^{-1}$ y$^{-1}$ when harvesting in June or September 2021, respectively, compared to no harvest, indicating a negative DM yield effect of harvest during the growing season. However, total N removal was increased from 44 to 75 kg N ha$^{-1}$ y$^{-1}$ when harvesting in September.

## Plant cover influences reactive nitrogen emissions after slurry application

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### Abstract

Dairy cattle slurry can be recycled as fertilizer, although attention should be given to ammonia ($NH_3$) and nitrous oxide ($N_2O$) emissions stimulated by its application. Our objective was to evaluate the effect of contrasting plant covers on these nitrogen (N) losses. The covers evaluated were: maize sown on an oats+vetch cover crop residue (CC-M) or on bare soil (M) and a 2-year pasture (P) composed of alfalfa and fescue grass. The slurry was applied in spring, at maize sowing, in C and CC, and after mowing in P, at a rate of 67 kg N $ha^{-1}$ (91 $m^3$ $ha^{-1}$).

Initially, M emitted more $NH_3$ through volatilization than CC-M and P (1.67±0.12, 1.04±0.12 and 1.22±0.12 kg $ha^{-1}$ $day^{-1}$ for M, CC-M and P, respectively). However, after 16 days from fertilization, CC-M emitted more $NH_3$ than M and P (0.11±0.01, 0.05±0.01 and 0.06±0.01 kg $ha^{-1}$ $day^{-1}$ for CC-M, M and P, respectively). Overall, total volatilization accumulated throughout the experiment was higher in CC-M than in M and P (9.75±1.34, 6.54±0.33 and 6.60±0.49 kg N-$NH_3$ $ha^{-1}$, respectively). On the other hand, during the 9 days that followed fertilization, CC-M presented a higher $N_2O$ emission rate compared to M and P, in association with soil moisture maintenance induced by mulching (e.g. on day 7: 37.60±3.02, 10.94±3.02 and 7.14±3.38 µg N $m^{-2}$ $h^{-1}$ for CC-M, P and M, respectively). Thereafter and until maize flowering, $N_2O$ emissions were similar among treatments and associated with soil moisture, which was determined by rain events.



WORK SHOP 2024 AARHUS

## Nitrogen intensity and its relationship with management, greenhouse gas emissions and land use occupation in Norwegian conventional and organic dairy systems

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### Abstract

Dairy farming yields milk and meat; however, production is linked with an environmental burden (Wattiaux et al., 2019). In our study N-intensity, GHG emission and land use occupation at 200 dairy farms from central Norway was calculated from cradle to farm gate. Nitrogen intensity was calculated as sum of N from purchased inputs, biological N-fixation, atmospheric N-deposition, N-surplus from off-farm production of ingredients for concentrates and roughage and of bought animals divided by N in delivered milk and meat (Koesling et al., 2017). The organic farms (n=15) had a lower N-intensity than conventional managed farms (n=185) (5.0 vs 6.9 kg N/kg N). Mainly explained by lower use of imported N in the organic farm group. The organic managed farms, however, had a higher land use occupation than conventional farms (3.6 vs 2.9 $m^2$ per 2.78 MJ edible energy in milk or meat delivered (2.78 MJMM)). The GHG emissions per 2.78 MJ edible energy in milk or meat was on average 1.4 kg CO2/2.78 MJMM edible energy for all farms (n=200). The GHG emission was correlated with N-intensity ($r^2$=0.85), which indicate that reduced N-intensity is associated with lower GHG emissions per product unit.

Our results support that improved utilization of local resources, e.g. manure, legumes in grass-based forage are likely to reduce N-intensity at both organic and conventional managed farms.

Reduced N-intensity will likely lessen GHG emissions. The reduced N-intensity and GHG emission came at an expense of increased land use occupation per produced product.

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## Circular economy approaches help identify levers to optimize nitrogen use in Polish mixed dairy farms

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### Abstract

Circular economy is a concept to minimize resource inputs by reducing energy leakage and closing material and energy loops, thus minimizing waste and emissions. Mixed dairy systems are particularly interesting cases for implementation of circular practices, especially when it comes to closing loops in nitrogen management due to better integration of plant cultivation and livestock husbandry, its effective reuse and hence decreasing the need for external inputs at all stages of the production process. Mixed dairy systems at international as well as national scales tend to show highly heterogeneous structures, however. Consequently, the improvement of circular practices on an individual farm may require a customized approach. Here we identify the production stages and the management options determining the use of nitrogen compounds in three mixed dairy farms from Poland with different herd number (from 26 to 52 dairy cows) and agricultural area (from 22 to 91 ha). We use a farm gate nitrogen budget approach to particularly consider the external nitrogen inputs (purchased fertilizers, fodder, and animals) and outputs (nitrogen losses as emissions or sold products), but we also investigate the crop and manure management operations inside the farm. Based on quantitative analysis of nitrogen fluxes and economic data collected during detailed interviews with the farmers, we also specifically look for nutritional and financial savings with special attention on the farmers' individual capabilities. Our results can serve as a source for optimizing the nitrogen cycling of compounds and guide towards adapting of circular practices by farmers more generally.

### Acknowledgement

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# AMMONIA AND METHANE EMISSIONS FROM A SWISS DAIRY FARM

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## Abstract

We conducted continuous measurements of NH3 and CH4 emissions for 61 days between November 9, 2021 and January 10, 2022 from a typical Swiss dairy farm in the Seeland region of Switzerland using the inverse dispersion method (IDM). The naturally ventilated loose housing system contained 51 lactating cows, 4 dry cows, 15 heifers and 31 calves. Line-integrated concentrations were measured with miniDOAS (NH3; Sintermann et al., XXXX) and GasFinder (CH4; Boreal laser XXX) instruments.

The estimated average emissions of 27 g NH3 $d^{-1}$ $LU^{-1}$ and 318 g CH4 $d^{-1}$ $LU^{-1}$ were in the range of literature values. A dependence of the higher frequency NH3 emission values on temperature was visible.

## Evaluation of Nitrification-Denitrification treated liquid manure as irrigation water for crops

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### Abstract

Intensive pig farming located in countryside can lead to soil and water pollution due to the over-application of manure as an organic fertilizer (Plaza-Bonilla et al., 2017; Zhang et al., 2017). Nitrification-Denitrification System Sequence Batch Reactor (SBR) is a technological alternative for reducing the environmental impact of intensive pig farming (Riaño & García- González, 2014).

The present study aims to determine the utility of SBR-treated liquid manure for irrigation. The experimental design established two treatments in a barley crop: Control - no irrigation or fertilization treatment (CT) and manure irrigation treatment (IT), which consisted of two irrigations of 25 mm each.

The soil was analyzed measuring N-P-K content, pH, and Electric Conductivity (EC) at five crop development times. At harvest, we analyzed vegetative dry matter (VDM), grain yield, and nitrogen-phosphorus-potassium (N-P-K) content in grain and VDM. Furthermore, we conducted analyses of the N-P-K content in leaves at four different stages of crop development. IT added to the crop an average of 85 nitrogen kg/ha, 35 phosphorus kg/ha, 302 potassium kg/ha, enhanced barley yield (82.7%), grain protein content (48.2 %), and VDM (134.4%) compared with CT.

Also, IT increased nitrogen content in the leaf at the beginning of the trial and leaf phosphorus and potassium content at the end of the crop development.

The study found that only EC had a statistically significant effect, while none of the other soil parameters showed a statistically significant impact.

This study shows that the irrigation of SBR-treated liquid manure may improve the sustainability of pig farms while increasing yields in organic farming.

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# Doing GOOD: defining a green operational outcomes domain for nitrogen use in NY corn silage production

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## Abstract

Opportunities to improve nitrogen (N) use efficiency for corn silage production in New York (NY) dairy systems can be identified by implementing adaptive N management and end-of-season evaluations. The objectives of this study were to (1) define operational or feasible outcome values for end-of-season field N use indicators in NY corn silage production to facilitate implementation of adaptive N management and farm assessments, (2) characterize N use indicators across a dataset of field observations. Data were collected for 994 corn silage field*year observations (10,048 ha) across eight NY dairies. For each observation, N balances (N supply - N uptake) and N uptake/N supply were estimated based on land-grant university (LGU) guidelines and farm management data. A green operational outcomes domain (GOOD) was defined. Feasible outcome values for N use indicators in the GOOD framework were established at a 50% minimum N uptake/N supply and a 159 kg N ha-1 maximum tolerable N balance. Feasible values were in partial agreement with previous literature, did not constrain P-based manure applications, and pointed at excessive N balances and low efficiencies in the context of adaptive N management. Large farm-to-farm differences existed, with 66% of observations meeting the GOOD feasible values and 34% displaying opportunities for N management refinement. The strategies with largest potential for enhancing N management include reducing N inputs in fields with low yields and high balances and evaluating non-N yield barriers (e.g. drainage, pests), increasing manure N utilization efficiency (with spring injection or incorporation), and crediting N contributions from sod.

## 2.7 Session 7: Nitrogen communication

## Challenge of nitrogen communications with multi-stakeholders

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### Abstract

Our nitrogen (N) use relates to production and consumption of food, goods, and energy, and everyone is therefore involved in the N issue, i.e., a tradeoff between the benefits of N use and the threats of accompanied N pollution. Successful communication among multi-stakeholders is a key to create inter- and trans-disciplinary knowledge to enable sustainable nitrogen (N) use for future generations. However, awareness of the N issue is still not widespread for many stakeholders and raising that awareness and facilitating communications underpinned by correct scientific knowledge are two major challenges. The Sustai-N-able project (SusN) (SusN, 2024) in Japan is taking up these challenges, i.e., N communications, in various ways with domestic stakeholders such as farmers, public, students, private sectors, local governments, ministries, and experts and international bodies like UNEP Working Group on N. In this presentation, two approaches will be introduced after overviewing the SusN project. One is to visualize the N issue using the systems thinking (Senge, 1990) and explore leverage points to spread awareness of the N issue, i.e., strategies of how to approach which stakeholders aiming effective results. The other is a methodology to earn unique ideas from a future perspective being imaginary future persons, i.e., Future Design (FD) (Saijo, 2021). Concrete examples of FD practices in Japan, e.g., future town plans, future agriculture adapted to climate change, and future ammonia uses, will be introduced. For those who are interested, we will provide an opportunity of mini-FD experience (25 min in total) after the session.

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## Developing a hands-on experience package on food and the environment from a nitrogen perspective

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### Abstract

Active participation of all relevant stakeholders is important for sustainable development, including environmental management (United Nations, 2012). Recently, campaigns and events have been held by local governments, companies, and scientists to disseminate information on environmental issues. However, it is difficult for participants to imagine their involvement in environmental issues because of the diversity in scale and causes and the intricate interrelations. Nitrogen (N) is an essential substance for ecosystems and humanity while it causes multiple N pollution. Scientific knowledge about the N cycle has been accumulated. One example is the development of the N footprint (NF) indicating the potential human-induced N loads to the environment (Leach et al. 2012). Nitrogen could be a new perspective to make people aware of the relationship between their life and the environmental. This study aimed to develop a hands-on experience package to disseminate scientific knowledge about N and to facilitate public communication on environmental issues including the N pollution. The package focused on food and was developed for adults in Miyakojima City, Okinawa Prefecture, Japan. This package consisted of four contents: exhibition of the N cycle in food system, hands-on experience of their food NF, intergenerational communication about their food items, and introductions to citizen activities for food and the environment. This package used for a public event on 23 February 2024. A questionnaire survey accompanied with this event indicated that 70% of the participants could feel the relationship between their life and the environment. Additionally, participants were motivated to collect N-related information and change their diet.

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## Eat without leaving a nitrogen footprint

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### Abstract

Communicating the importance of nitrogen to the general public is crucial to promoting awareness about its critical role in maintaining life and ecosystems. Nitrogen makes up about 78% of Earth's atmosphere and is a fundamental component of proteins, DNA and chlorophyll, making it essential for all living organisms. However, its low use efficiency and excessive use in fertilisers contributes to environmental issues such as water pollution and greenhouse gas emissions. By educating the general public about the importance of nitrogen, we empower individuals to make informed choices about their consumption habits, regarding the provenance of the ingredients they consume. Good agricultural practices and environmental management are fundamental to improving the efficiency of nitrogen use and reducing nitrogen losses to the environment, but so are personal choices in relation to food consumption. In this regard a chef, a scientist and a nutritionist gathered to produce a recipe book where full meals recipes for a fortnight were analised for their nutritional quality and their environmental impact regarding nitrogen lost in production expressed as nitrogen footprint of each recipe calculated using the Capri model. This is the first book ever published to raise awareness about the consequences of consumer choices to personal health and to the environment, through the display of the nutritional greenlight and the total reactive nitrogen lost into the environment from each recipe. Raising awareness of the impact of nitrogen can drive policy change, promoting sustainable practices and reducing environmental degradation.

### Aknowledgements

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## 2.8 Session 8: Nitrogen in organic farming

Compost used as mulch in vegetable production can lead to nitrate leaching

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## Abstract

Deep compost mulch or "No Dig" is a cultivation method that is mainly used on small-scale market garden farms, where vegetables are mulched with compost at a high application rate (Frost 2021). The farms are characterized by closely spaced crops, several successive sets of vegetables in a bed, and a high labour input. The application of a 15-cm thick, permanent layer of compost regulates weeds, enables no-tillage, reduces soil evaporation losses, and regulates soil temperature. In addition, nutrients are released from the mulch, which can lead to increased yields, but also harbours the potential for nitrate leaching. To date, there has been a lack of studies on the nutrient dynamics of compost mulch to confirm this.

In our study we investigated a vegetable farm applying 15-cm layer of biowaste compost. Soils were sampled monthly at 0-0.9 m depth. 450 kg mineral nitrogen (Nmin-N)/ha accumulated at a depth of 0.6-0.9 cm over the course of the year, which represents a N leaching risk (Ruch et al., 2023). Modelling with decision support tools, such as NDICEA (https://ndiceaweb.eu/) and N-Expert (https://n-expert.igzev.de/), confirmed the high leaching potentials, especially when using biowaste compost. Woody green waste composts have a lower N concentration, a higher C/N ratio and a lower bulk density. Using these instead of biowaste composts can help to obtain sufficient mulching heights with lower N application and mineralization rates, which reduces N leaching risks.

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## Green ammonia: future opportunity for moderate spring fertilisation of organic winter cereals?

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### Abstract

In the near future, we will (hopefully) live in a de-carbonised economy and CO2-neutral produced N-fertiliser from green ammonia will be standard in conventional agriculture. With very few negative environmental impacts, the use of mineral N fertiliser from green ammonia might become an option in organic winter crops under European conditions within strictly limited and regulated doses only in early spring. Due to cool soil temperatures during beginning of spring growth the plant N demand cannot usually be met from soil N mineralisation. This is a crucial asynchrony during the relevant sink formation between double ridge and terminal spikelet stage. Ensuring a maximal sink formation through sufficient N supply during this sensitive phase is a key for closing the yield gap by increased resource use efficiency.

From a long-term trial (established in 1974 at the experimental farm 'Hohenschulen' of Kiel University) with varied N rates (0, 40, 80, 120) at three split applications (start of spring growth, stem elongation, ear emergence) in full-factorial combinations (overall 64 N treatments) and additional fungicide treatments (no, reduced, full) in winter wheat and winter barley we can get some initial insights of the potential from moderate mineral N-fertilisation in low-input cropping systems. The trial enables, furthermore, to assess the options for increased N use efficiency through re-allocation between N-input-intensities.

Low-N-input showed the steepest yield response (double yield increase per kg N compared to typical conventional intensity). Fertilisation between 25 to 50 kg during the first split could reduce the yield gap from 39% to 25-30% with very low risk of environmental damage.

# Measured soil water nitrate concentration in organic and conventional vegetable production.

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## Abstract

Vegetable production in Denmark is becoming a priority as more individuals adopt diets that are dominated by vegetables. Organic and conventional vegetable farming practices may contribute to nitrate leaching. Unfortunately, the nitrate leaching measurements at field-level being specifically tied to vegetable production are scarce. Therefore, this study aims to measure and assess nitrate concentration in varying vegetable crop rotations and agricultural practices (conventional and organic) in Denmark over two years. Various crop rotations including iceberg lettuce, red onion, leek, savoy cabbage, pointed cabbage, potato, pea, winter wheat, winter rye, grass-clover and grass were considered in 11 fields. Nitrate concentration from suction cups were measured in 0.6m in sandy soils and 1 to 1.2m in loamy soils, in four replicates, every two weeks during drain season and monthly in summer. Results showed that organic practices registered lower nitrate concentrations in both potato and leek fields compared to conventional practices. However, the yields were lower in organic practices. Conventional potato had the highest nitrate concentrations (>30 $mgL^{-1}$) during July to November, whereas conventional leek had the highest concentrations from October to January and a higher peak (>50 $mgL^{-1}$). The highest concentration across all fields was observed in conventional onion two months after harvest, suggesting legacy effect of high fertilizer application coupled with low N uptake from onion farming. Furthermore, nitrate concentration was elevated in vegetable fields compared to grass and cereal fields. Overall, the results indicate that organic farming practices and diverse crop rotations can decrease nitrate leaching from vegetables production systems.

Keywords: Crop rotation, organic farming, nitrogen leaching, vegetable production.

# Compost along with plant-based fertilizers increases plant nitrogen content and soil microbial activity in organic parsley

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## Abstract

Plant-based fertilizers and composts can play an important role in organic vegetable production systems when availability of animal fertilizers is insufficient. Depending on the type, plant- based fertilizers can promote circular economy, recycling and waste valorization. There is a lack of knowledge of the combined effect of plant-based fertilizers as fast releasing nitrogen sources and compost as soil improvers (Shanmugam et al 2022).

We hypothesized that combining plant-based fertilizers and compost can provide sufficient nitrogen fertilization while improving soil quality and nitrogen use efficiency compared to plant-based fertilizers alone. For this purpose, we conducted a fully randomized greenhouse pot trial, where parsley (Petroselinum crispum var. neapolitanum) was grown with four plant-based fertilizers: dried clover, silage clover, dried seaweed (toothed wrack) and residues coming from the grass protein industry; either with or without a compost made from vegetable residues. Nitrogen application rates were equal in all treatments. Plant yields, nitrogen uptake, soil enzyme activity (dehydrogenase) and soil mineral nitrogen content were analyzed.

Compost addition increased soil mineral nitrogen content at mid-season as well as plant nitrogen content at harvest. No effect of compost was seen on yields. Dried clover treatment had the highest yield followed by silage clover, grass protein and seaweed. Preliminary results show significant interactions between compost and plant-based fertilizers on dehydrogenase activity indicating a positive synergetic effect on soil microorganisms when selected plant-based fertilizers are combined with compost. Our study indicates that combined application of compost with plant-based fertilizers can be a potential fertilizer strategy for organic vegetable production.

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## Nitrogen flows from digestate application in an organic arable crop rotation: Potential for improvement by manure treatment?

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### Abstract

Nitrogen (N) availability often limits yields in organic agriculture. Use of anaerobically digested manure and organic wastes may overcome this deficit, but remains controversial among organic farmers and needs to minimize potential tradeoffs like increased ammonia (NH3) losses, nitrous oxide (N2O) emissions or nitrate (NO3) leaching. We have conducted a field experiment on an organic farm in Switzerland with different digestates in comparison to undigested liquid manure, mineral fertilization and a zero N control since 2018 (Efosa et al. 2023). Besides monitoring N flows and soil quality, we are investigating biochar amendment, slurry acidification and NH3 stripping for their potential to decrease N losses. Annual total N application rates vary between 120 and 140 kg N/ha, depending on the crop. While crop yields generally range in the order mineral N = liquid organic fertilizer > solid digestate = zero N control, crop N uptake and apparent N use efficiency (NUE) are typically greater with mineral N than with any other organic fertilizer. The more subtle differences within differently treated liquid organic fertilizers are becoming more consistent with increasing duration of the experiment, revealing tradeoffs with respect to NUE, N losses and soil quality. Emissions of N2O and methane show some unexpected interactions of the fertilizers with the different manure treatment approaches. While use of digestates could reduce N limitations in organic cropping, the pros and cons of biochar amendment, acidification and NH3 stripping with respect to NUE, N losses and climate impact will be discussed.

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## Effect of Different Doses of Zeolite in an Organic Fertilizer on the Emission of $NH_3$ and $N_2O$ & Plant Yield

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### Abstract

Zeolite has high cation exchange capacity (CEC) and surface area, so the addition of zeolite can thus hold more $NH_4^+$ than conventional organic nitrogen fertilizers, and may reduce greenhouse gas (GHG) emissions, by increasing N use efficiency. However, the dosage of zeolite in organic fertilizers is not yet clear. Therefore, a 56-day incubation experiment with ryegrass (Lolium perenne) was conducted with following treatments: (1) no fertilization + no zeolite (blank control), (2) 120 $g{\cdot}N{\cdot}m^{-2}$ N + no zeolite (NZ0), (3) 120 $g{\cdot}N{\cdot}m^{-2}$ N + 0.5% zeolite (NZ1), (4) 120 $g{\cdot}N{\cdot}m^{-2}$ N + 1% zeolite (NZ2), (5) 120 $g{\cdot}N{\cdot}m^{-2}$ N + 2% zeolite (NZ3), (6) 120 $g{\cdot}N{\cdot}m^{-2}$ N fertilization + 5% zeolite (NZ4). The organic nitrogen fertilizer is produced from cattle manure by unaerobic digestion. Zeolite (Klinoptilolith) was added into the biogas digestate one day before fertilization. Cumulative $NH_3$ emissions of NZ1, NZ2, NZ3 and NZ4 were 26.6%, 31.3%, 31.9% and 27.1% lower than NZ0, however, there was no decrease in $N_2O$ emissions and no yield increase in zeolite added treatments, which may be due to the short rinsing time of zeolite and organic fertilizers. We suggest that future study should add zeolite before the anaerobic digestion of cattle slurry. The microorganisms in the digestate can better attach to the zeolite, forming a biofilm, and better preserve $NH_4^+$ in the digestate, reducing $NH_3$ and $N_2O$ emissions and has the potential to increase yield.

## Nitrogen flow network and energy performance in contrasted organic farms

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### Abstract

Organic farming (OF) practices have gained considerable attention due to their potential to mitigate environmental impacts and promote sustainable agriculture. Unlike conventional agriculture, OF uses more diversified nutrient management practices. Yet, OF practices are not fully documented (Chmelíková et al., 2021). Here, we investigate the nitrogen (N) and energy flows in OF systems, with different fertilization and feed practices. Through a combination of material flow and ecological network analysis, we assess farm N circularity (Rufino et al., 2009) and its energy functioning (Harchaoui and Chatzimpiros, 2018). The study examines eight different organic farming systems including vegetable, mixed crop-livestock and cereal farms located in Brittany, France. Our main findings highlight that mixed-crop livestock farms exhibit 1.5 times greater N self-sufficiency, yet they are 25% and 80% less N efficient than vegetable and cereal farms, respectively. Energy consumption decreases as the proportion of grassland increases. By considering the sources of feed and manure import, we show that on average 70% of total N input originates locally (<50 km) across all farms. The availability of local N manure and feed resources surrounding the farm plays a critical role in the overall farm N network flow design. Mixed crop-livestock farms emphasize N recycling within the farm, resulting in a Finn index averaging 0.4 to 0.6, where both vegetable and cereal farm display no recycling rate. This study provides valuable insights into the internal functioning of OF from a dual N and energy perspective.

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# Can organic vegetable production be intensified in a sustainable way?

Investigating nitrogen use efficiency and leaching risk in a five-year crop rotation

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## Abstract

Sustainable intensification systems in vegetable production aim to enhance productivity by implementing innovative and improved farming practices on farmland, while minimizing negative environmental impacts (Pretty and Bharucha, 2014). Simultaneously, these systems strive to improve nitrogen availability and soil health. But is it possible to sustainably produce nitrogen demanding vegetables in an intensified crop rotation? We developed a sustainable intensification system (SI) by combining multiple crops per season, plant-based fertilizers, cover crops, and reduced tillage in a 5-year organic crop rotation, and compared to an organic crop rotation based on common practices (CP) using one crop per season, liquid animal manure, few cover crops and plough tillage (2017-2021) on a sandy loam under organic farming since 1996 (Hefner et al., 2022, 2024). The SI achieved marketable yields comparable to CP throughout the five years. Initially, the systems had similar nitrogen use efficiency (NUE), but after 5 years, SI showed a reduced NUE. Both systems reduced total organic carbon content. This indicated a decline in soil organic matter regardless of the system used, highlighting the deteriorating impact of intensive vegetable production. Despite the loss of total organic carbon, SI increased soil dehydrogenase activity, indicating more favorable conditions for microbial communities in the SI system. Our results underscore that SI can maintain equal yields to CP but also highlight the negative effect of intensive vegetable production in general. This emphasizes the need to develop a new strategy aiming to improve soil organic carbon in vegetable production systems.

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## Nitrogen Transfer from pea to oat – a field study

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### Abstract

The current study quantified nitrogen (N) transfer from peas to oats under field conditions to assess the effects of intercropping. The data obtained were compared with previously published pot and field experiments. Pea (Pisum sativum L. cv. Santana) and oat (Avena sativa L. cv Dominik) plants as intercrop were grown for 105 days under field conditions at the University of Kassel in Germany. Pea plants were labelled with a solution of 0.5% $^{15}$N urea (95 atom%), using the cotton wick technique. At dry ripeness, plants were harvested and separated into grain, stem, and leaves and roots. For calculating nitrogen rhizodeposition (as described in Hupe et al. 2016) and measuring microbial biomass and mineral N, soil samples were taken at 0-30 cm depth.

It was found, that pea rhizodeposits reached 17 kg N ha$^{-1}$. Nitrogen derived from rhizodeposition (NdfR) contributed 12.7% to total pea N and in the intercropped oat nearly 30% N as NdfR were found.

A 2.5-times higher contribution of NdfR to pea total N was measured in peas intercropped with the cereals, comparing the current field study with previously published pot and field experiments. In addition, the amount of NdfR transferred to microbial biomass was higher in pot experiments compared to field experiments. The main reason is the higher root density in pots, followed by a higher microbial root turnover. Future studies on intercropping should regularly consider root formation and more often rhizodeposition.

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## Exploring soluble organic N compounds in soil after 10 years of compost and biochar fertilization

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### Abstract

The soluble organic nitrogen fraction in agricultural soils plays crucial roles in soil nitrogen cycling and microbial metabolism (Myrold, 2021). This active N pool is particularly relevant in organic farming since it represents the main N source for plant nutrition. Our research group is running a long term experiment investigating the long term impact of organic amendments, based on compost, biochar and their mixture, on an organically managed olive orchard in South Spain (Sanchez-García, 2016). In this study we investigated the levels and composition of water soluble organic nitrogen (SON) in soils. After 10 years of biennial application, compost and compost enriched with biochar caused a significant enrichment in SON (60.02 and 66.99 mg/kg) compared to the biochar treatment (14.19 mg/kg) and the control (10.98 mg/kg), which received no amendment. The most abundant components of the soluble organic nitrogen fraction in the amended treatments were identified as small peptides, amino acids such as leucine, glutamate, proline and phenylalanine, alongside other nitrogen-containing compounds derived from plant residues and microbial biomass including betaine, ectoine, carnitine and with minimal presence of N-acetyl hexosamines. Both compost amendments caused an increase in these valuable compounds, serving as a reservoir of essential nutrients and osmoregulative compounds in soil.

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