Proceedings of the XXI International Nitrogen Workshop

Halving nitrogen waste by 2030
24th – 28th October 2022

School of Agricultural, Food and Biosystems Engineering - Universidad Politécnica de Madrid. Spain

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Foreword

Integrating spatial and system scales to halve nitrogen waste by 2030

Agro-food systems are fuelled by nitrogen (N). New N enters the cropping and grassland systems in the form of synthetic fertilizer or by means of biological fixation. N present in the proteins of crops, local or imported, and grasses can be transferred to the livestock or directly to us, humans, arriving in our plates after travelling along the supply chain. Part of the N embedded in livestock manure and in crop residues can be reused through adequate manure and soil management. Despite the benefits of recirculation, today about 80% of the new N entering the agro-food systems at the global scale is lost to the environment before reaching our plates. We refer to this loss as nitrogen waste (Sutton *et al*., 2021). The N emitted to the environment triggers substantial negative impacts, including water and air pollution, biodiversity loss, and greenhouse gas emissions. Nevertheless, not having enough N threatens agricultural production and food security. Therefore, reducing N waste is clearly a paramount objective for humankind.

The agro-food system comprises several interconnected compartments where N can leak. Therefore, achieving food security based on sustainable systems for the coming decades requires a detailed understanding of the functioning of each compartment and the complex links between crops and livestock systems as well as their integration into agro-food systems. The proposed solutions have to be based on sound science embracing this complexity. To do so, we need a multidisciplinary and a multiscale approach along with the involvement of the different stakeholders.

The XXI International N Workshop aims to contribute to this challenge, and it is a structure following a system scales organization based on Zhang et al. (2020). This book includes the 299 communications by authors from 38 countries presented at the meeting, including in-person and online presentations. Several keynotes by reputed specialists integrate essential and new breakthrough knowledge from diverse perspectives and scales. These contributions cover different spatial scales (from the plot to the world) and system scopes (crop, livestock, mixed, agro-food, and landscape systems).

Contributions to the plant–soil system (crops) session include studies assessing N losses to the air and waters and greenhouse gas emissions in cropping systems and grasslands, practices to improve NUE, and the efficacy of enhanced-efficiency fertilizers. The livestock system session includes contributions promoting reduction of N losses through feeding and housing strategies. The mixed systems session deals with emissions during manure management, N cycling at the farm or farming system level and decision support systems, as well as system-integrated assessments. The agro-food system session includes contributions working with the N footprint as well as approaches considering the full chain and the effect of the demand-side measures. Finally, the landscape system session comprises approaches considering the territory and the spatial dynamics involving agriculture and other non-agrifood system emissions in river basins or even at the global scale.

Four additional special sessions consider complementary aspects of great importance today. The special session on remote sensing for N optimization and precision agriculture aims to discuss the potential of using sensors, digitalization, and artificial intelligence to optimize N use in cropping systems. The session on the costs and benefits of halving N waste by 2030 discusses the economic valuation and cost–benefit analysis to design and evaluate integrated N management and policies. In the session on N and the circular economy, the question "Where is the circular N?" is posed and includes communications on N recovery, N biofertilizers together with a discussion about the role played by the stakeholders. Lastly, the session on policy strategies analyses the existing national policies to reduce N pollution in addition to proposing new approaches to N governance across sectors and scales.

The exciting science of this meeting is summarized in this book of abstracts. We hope that this collective effort contributes to advancing the scientific knowledge and its transfer to society, resulting in actual reductions in N waste. This has been possible thanks to the significant contribution of all the authors submitting their work as well as the 34 members of the scientific committee and the 15 members of the organizing committee. We are also very grateful to the conference sponsors and collaborators.

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Index

Keynote 1

Regular Session "Crops 1"

Special Session "Costs and benefits 1"

Regular Session "Livestock 1"

Abstract title & authors **Page**

Keynote 2

Abstract title & authors **Page**

Regular Session "Crops 2"

Special Session "Policy 1"

Regular Session "Livestock 2"

Abstract title & authors **Page**

Poster Session 1.1

Abstract title & authors **Page**

Poster Session 1.2

Abstract title & authors **Page**

Poster Session 1.3

Poster Oral Session Policy and Cost benefit

Keynote 3

Regular Session "Crops 3"

Special Session “Costs and benefits 2”

Abstract title & authors **Page**

Regular Session “Livestock 3”

Abstract title & authors **Page**

Regular Session "Agro-Food 1"

Abstract title & authors Page

Regular Session "Livestock 4"

Abstract title & authors Page

Keynote 4

Abstract title & authors	Page
Improvement and refinement of the UK inventory of nitrous oxide emissions from agriculture. *Laura Cárdenas*	142

Regular Session "Crops 4"

Special Session "Policy 2"

Regular Session "Livestock 5"

Keynote 5

Regular Session "Crops 5"

Regular Session "Livestock 6"

Special Session "Remote sensing 1"

Regular Session “Agro-Food 2” + “Landscape 1”

Abstract title & authors **Page**

Special Session “Remote sensing 2”

Abstract title & authors **Page**

Keynote 6

Abstract title & authors **Page**

Regular Session "Crops 6"

Abstract title & authors **Page**

Regular Session “Landscape 2”

Special Session “Remote sensing 3”

Poster Session 2.1

Abstract title & authors **Page**

Poster Session 2.2

Abstract title & authors **Page**

Poster Session 2.3

Abstract title & authors **Page**

Keynote 7

Poster Session 3.1

Poster Session 3.2

Poster Session 3.3

Regular Session “Crops 7”

Regular Session "Landscape 3"

Special Session "Circular economy 1"

Keynote 8

Regular Session “Crops 8”

Regular Session “Landscape 4”

Special Session “Circular economy 2”

Abstract title & authors — Page

Poster Remote

Abstract title & authors — Page

Crops

Livestock

Mix systems

Remote Sensing

Landscape

Circular economy

Conclusions

Title & authors **Page**

Halving nitrogen waste: motivation, definitions and opportunities for 2030 and beyond.

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While major gaps in knowledge remain, the major reactive nitrogen (N_r) flows are well-characterized in many regions, informed by a combination of experimental studies, ground-based and satellite observations, and numerical models. While the evidence shows clear benefits and threats of anthropogenic N_r mobilization, the question now becomes ever clearer: what is society going to do to address the challenge?

This presentation reflects on the development behind the idea of "halving nitrogen waste" globally, considers the need to develop consensus around definitions, and considers options for action by 2030 and beyond.

Nitrogen narratives have developed over the last 20 years, including the idea of nitrogen as a multi-threat, multi-benefit issue. This has emphasized the need for communication tools, such as the WAGES perspective, where action on nitrogen simultaneously benefits **W**ater, **A**ir quality, **G**reenhouse balance, **E**cosystems and **S**oils. Since then, a sequence can be detected from "reduce pollution" (socially negative for polluters), to increase nitrogen efficiency (socially positive, but hard to set shared goals), to reduce nitrogen waste (socially positive for all, easy to set shared goals, emphasizes economic benefit).

It is explained how the phrase "halve nitrogen waste" originated in January 2018 during the INMS New York workshop (Sutton et al., 2021). "Half" was selected to frame the need for bold action. "Waste" was chosen to express the waste of resources/money, by halving which, everyone could benefit. The concept was launched by INI (October 2018) and embraced by 14 UN member states in the Colombo Declaration (October 2019). A linked aim to "significantly reduce nitrogen waste by 2030 and beyond" was adopted by all member states in the UN Environment Assembly Resolution 5/2 (March 2022).

Action to halve nitrogen waste will be accelerated by the tripling of nitrogen prices since 2019, now representing a global economic opportunity worth USD 300 billion per year. Options in agriculture, wastewater, municipal solid waste, combustion processes, consumption and integration are presented with a view to accelerating action. The gross financial benefit of action to halve nitrogen waste is now even larger than the USD 200 billion of public money that is used globally to subsidize farmers.

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Environmental N losses from Chinese and global vegetable production systems

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Vegetable production in greenhouses is often associated with the use of excessive amounts of nitrogen (N) fertilizers, low NUE (15-35%), and high N losses along gaseous and hydrological pathways. On basis of a thorough meta-analysis accompanied with detailed field measurements in various regions of China, we assessed the effects of application rate, fertilizer type, irrigation type and amount, and soil properties on soil N_2O emissions and nitrogen leaching from greenhouse vegetable systems on the basis of 75 studies. Our studies show that at global scale annual mean soil N_2O emission from fertilized greenhouse vegetable systems are about 12.0 ± 1.0 kg N_2O-N ha^{-1} yr^{-1}, but that specifically in China, where farmers use huge amounts of organic N fertilizers, annual N emission rates by far exceeding 50 kg N_2O-N ha^{-1} yr^{-1} may occur. The mean annual nitrogen leaching (NL) was 297 ± 22 kg N ha^{-1} yr^{-1} (global: 1.66 Tg N yr^{-1}), with fertilization, irrigation, and SOC explaining 65% of the observed variation (Qasim et al., 2021). Also here, own field observations show, that N leaching rates may exceed 500 kg N ha^{-1} yr^{-1}, with leaching of dissolved N (DON) contributing about ¼. Global yield-scaled N_2O emissions (0.05 ± 0.01 kg N_2O-N Mg^{-1} yr^{-1}) and nitrogen leaching (0.79 ± 0.08 kg N Mg^{-1} yr^{-1}) strongly depended on fertilizer rates. Overall, rates found documented in our meta-analysis as well as in our field studies, may still represent an underestimation as only single studies investigated N losses during periods of anaerobic soil disinfestation (ASD), a method carried out every 2-3 years during fallow periods to combat soil-borne diseases and to improve soil health (Qasim et al., 2022).

In field studies in the North of China and in Shandong province various options for mitigating N losses during greenhouse vegetable production were tested, with introduction of drip fertigation in combination with reduced N fertilization rates being the most promising one. However, additional incorporation of maize straw or biochar are as well suitable measures to reduce N losses, while at the same time increasing soil C stocks.

Overall, our study shows, that while global greenhouse vegetable production systems are hotspots for environmental N losses, specifically regarding N leaching, economically feasible adaptations of the production system may allow for signification mitigation.

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Application technology and slurry type affect slurry acidification effect on ammonia emissions and crop response

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Field slurry acidification with sulfuric acid has been discussed as a major mitigation measure to reduce ammonia (NH_3) emissions from field applied liquid organic fertilizers. Commercial systems available for farmers operate according to single point acidification, i.e. addition of acid between slurry tank and application tube during slurry application. However, scientific experimental testing of field acidification has been mainly confined to acidification proxy-systems in which acidification is often done the day before slurry application and eventually re-adjusted before slurry application. Two field studies were carried out with commercially available technology. In a trial in Denmark (Wagner et al. 2021) acid amount needed for single point pH adjustment was tested in the lab before system application. In the same experiment, 5 different slurry types (cattle, pig, mink, anaerobic digestate, liquid phase separated digestate) with (target pH 6) and without acidification were tested in 2 winter wheat campaigns, while combinations of acidification with different slurry application systems were investigated in summer barley. Yield components were determined after plot combine harvest. In a trial carried out in central Germany, another commercial system was used applying liquid phase, chicken-manure based digestate on grassland at 2 acid dosage levels. In both trials, NH_3 losses were measured by a combination of sulfuric acid trap samplers scaled by DTM dynamic chamber measurements (Pacholski, 2016). Apart of pig slurry, acidification significantly reduced ammonia emissions in all slurry types by about 50%, while crop effects were mainly observed in nitrogen uptake and apparent nitrogen use efficiency. Amount of added acid rather than pH reduction increment accounted for observed NH_3 reduction effects. Combination of slurry incorporation (harrow) with acidification resulted in NH_3 mitigation on the same level as closed slot injection. In the grassland trial, even very high acid application levels (5 l sulfuric acid per m^3) resulted in a smaller reduction of emissions (35%). Tested single point acidification systems significantly reduced ammonia emissions in most trial situations. However, care should be taken regarding choice of acidification target values (slurry pH vs. amount of acid) and technical system limitations for slurry substrates demanding high dosage of acid.

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Methodology for recording ammonia emissions in field trials - are we measuring correctly ?

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Introduction

The application of nitrogenous fertilisers - both livestock manure and mineral fertilisers - is one of the main sources of national and global NH_3 emissions. It is therefore absolutely necessary to have emission measuring methods that are as simple, accurate, inexpensive and correct as possible in order to obtain representative data for a large number of regions, crops and cultivation specifics.

Identification of a reference method for the quantification of ammonia emissions

The correctness of the IHF method (Integrated Horizontal Flux Method) was tested in two field trials. In a first trial, viscous cattle slurry was applied to a harvested wheat stubble field on the circular experimental area. The straw was chopped and evenly distributed over the plot so that only small amounts of the slurry were in contact with the soil. NH_3 emissions were recorded over a measurement period of 50 h using the IHF method. In the second field trial on a harvested grain field, an ammonium-containing solution filled into small aluminium pans served as an ammonia source. The pans were also arranged in a circular pattern and the emissions were recorded by the IHF method over a period of 6.5 hours.

Results and conclusions

The measurement and model calculations with the IHF method showed NH_3 emissions of 96 % of the applied ammonium-N within one day in trial 1, after which no more emissions were detectable. Significant residual levels of ammonium on the straw were not detectable. In trial 2, 95 % of the ammonia emitted from the pans was recorded by the IHF method.

It can therefore be assumed that the IHF method correctly displays the emissions at elevated ammonia source strength conditions. The IHF method should therefore be considered as a reference method for ammonia emissions in the field, but further investigations are required (Döhler et al. 2021; Döhler and Wiechmann, 1988).

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Is nitrogen management alone sufficient to mitigate nitrate, nitrous oxide, and ammonia loss from cornfields?

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Enhancing crop productivity while mitigating the negative environmental impact of agriculture with advanced nitrogen (N) management practices is fundamental, but is N management alone sufficient to achieve it? The objectives of this 7-year study (2014-2020) were to evaluate pre-plant urea (traditional management) and enhanced efficiency fertilizers and split applications (advanced management) on corn (*Zea mays* L.) grain yield and N loss to the environment as nitrate (NO_3) leaching and nitrous oxide (N_2O) and ammonia (NH_3) emissions to the atmosphere. The study was conducted in Lamberton Minnesota, USA. The study was replicated four times in a randomized complete block design with four treatments with an agronomic-optimum N rate: pre-plant application of 202 kg N ha^{-1} of either urea (U) or ESN (E), which is a polymer coated urea, and 135 kg N ha^{-1} as urea with the urease inhibitor Agrotain (U+) sidedressed at development stage V4-6 with 67 kg N ha^{-1} applied before planting as either urea (U/U+) or ESN (E/U+). The E/U+ increased corn grain yield (1 Mg ha^{-1}) and total N uptake (18 kg N ha^{-1}) compared to U, while E and U/U+ produced no differences. A trend for greater net economic returns per hectare was observed with E/U+ than U (US$63), E (US$52), and U/U+ (US$46). Nitrate loss was lower for E than the other treatments, but flow-weighted concentrations showed only a lower trend. Nitrous oxide emissions were not reduced with split application or U. However, they were reduced with E in wet years, but there were no differences in dry years or seasons with evenly distributed precipitation. Ammonia loss was lower for E compared to other treatments. Overall, U was least efficient, producing lower crop yields and increasing N losses compared to E in wet years. While split treatments increased corn yield, they did not reduce N losses, thus they may not be as environmentally advantageous. While improved production and environmental protection can be achievable by refining N management practices, they are insufficient to substantially reduce N loss.

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Use Efficiency and Loss of Nitrogen in Wetland Rice Field Under Nitrogen Fertilizer Management: Field Observation and Multispectral Image Analysis

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Abstract

The study attempted to increase nitrogen use efficiency (NUE) and reduce nitrogen (N) losses in two consecutive rice seasons of boro (dry season), and aman (monsoon) during 2020-2021 under different nitrogen fertilizer managements in Gazipur, Bangladesh. It also assesses and quantifies nutrient contents and yield using multispectral unmanned aerial systems (UAS) data collected on seven growth stages of aman rice. There were seven treatments viz. (i) zero N control, (ii) recommended dose (RD) of N as prilled urea (PU), (iii) RD + 25% PU, (iv) RD - 25% PU, (v) cowdung (2 t/ha) + supplemented by PU, (vi) RD + biochar, and (vii) urea deep placement using urea super granule (USG). Recommended doses of N fertilizer as PU were 186 and 102 kg/ha for boro and aman rice, respectively, while as USG were 95 and 75 kg/ha, respectively. Ammonia (NH_3) volatilization and nitrate (NO_3^-) leaching were determined. In both the growing seasons, NH_3-N emission was found the lowest in the USG treatment followed by biochar and cowdung treatments. The minimum NO_3^- leaching loss was recorded in the USG in both rice seasons. The highest grain yields of both rice were attained in the biochar followed by USG and cowdung treatments. The highest agronomic (28.51 kg/kg), physiological (48.36 kg/kg) and recovery (58.98%) efficiencies of N were found in USG followed by biochar and cowdung treatment in boro but recovery (62.56%) efficiencies were found in biochar treatment followed by USG and cowdung treatment in aman season. UAS data also confirmed that, the recommended dose with biochar showed better grain and biological yields. In biochar treatment, the highest levels of nitrogen (1.70%), phosphorus (0.21%), potassium (1.48%) and sulfur (0.17%) were found in the canopy, followed by cowdung and USG. The findings revealed that USG and biochar treatments appeared promising to reduce ammonia volatilization and nitrate leaching, and increase NUE and grain yields.

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CULTAN fertilization with urea ammonium sulfate: Impacts on field NH_3 emissions and N-use efficiency

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About 12% of agricultural NH_3 emissions originate from the application of synthetic nitrogen fertilizers in Germany. Through the Convention on Long-range Transboundary Air Pollution, Germany has committed to reducing its total NH_3 emissions by 27% by 2030 compared to the reference year 2005. As part of the joint research project NH3-Min, we conducted a multi-plot field experiment on winter wheat, set up at 10 sites across Germany. We measured NH_3 emissions daily for up to two weeks after application of different nitrogen-containing synthetic fertilizers. Additionally, we monitored soil mineral nitrogen dynamics, pH, weather conditions and various plant parameters, such as yield, biomass and protein content. 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 ammonia emissions and 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. Ammonia emission were quantified by means of plot based acid traps and simultaneous dynamic chamber measurements (Pacholski, 2016). Using our data, we will compare ammonia emissions 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 in similar NH_3 emissions after the initial application as its counterpart, i.e., solid urea ammonium sulfate, but that NH_3 emissions from CULTAN decreased to almost zero thereafter, while NH_3 emissions after the second and third surface application of solid urea ammonium sulfate were as high as after the first application. This difference corresponded at one site to an overall reduction in NH_3 emissions of 70%, or 14.5kg N/ha by CULTAN fertilization. The residual 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 for the reduction of ammonia emissions and increasing nitrogen use efficiency.

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Global costs and benefits of nitrogen use and losses in 2010 and 2050 under Shared Socioeconomic Pathways

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Nitrogen (N) use benefits food production and carbon sequestration, while nitrogen losses can cause severe damages to environmental quality, human health, ecosystems and affect the greenhouse gas (GHG) balance. Assessment of the societal costs and benefits of these multiple effects can inform policy about the associated welfare loss and the relative contribution of nitrogen in pollution issues and food production. These N shares and welfare effects vary widely between world regions and can inform design of N policies and mitigation options. For the International Nitrogen Management System project, costs and benefits were monetized for the following N issues: change of (1) mortality by ambient $PM_{2.5}$ and O_3 due to change of N emission to air (Gu et al., 2021); (2) cereal production and N surplus by change of fertilizer use (van Grinsven et al., 2022) and exposure to O_3; (3) climate effects of N-related changes to the GHG balance, elaborating the effect of N deposition on carbon sequestration; (4) ecosystem services of marine ecosystems due to change of N river inputs and (5) biodiversity of terrestrial ecosystems by change of atmospheric N deposition. In view of considerable uncertainties and conceptual debates about valuation of environmental impacts, presentation of results will focus on changes of values between current (2010-2015) and contrasting scenarios for 2050 (Shared Socioeconomic Pathways; viz. SSP1, SSP2 and SSP5, with contrasting climate and N policies) and between thirteen world regions. (results forthcoming).

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A Cost-Benefit Analysis of Water Framework Directive implementation in Denmark towards 2027

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The aim of the WFD is to achieve good ecological status of water bodies by 2027. EU-countries are busy deciding on the measures needed to achieve this target in the last planning period. The WFD accepts exemptions to the environmental objectives in cases where achieving good ecological status is disproportionately costly when compared to the environmental benefits. However, few countries have succeeded in such an analysis and so the wish for exemptions is often not founded in actual CBA analyses. In a previous paper an approach to screening of catchments has been presented (Jensen et al., 2013).

In this new analysis, an effort has been made to improve both the cost and especially the benefit estimates. For each catchment area, the current water quality status is identified and the costs of achieving good ecological status are determined. The cost estimates include a range of non-point pollution measures in agriculture and urban wastewater (overflow and from sewage works). Benefit assessment is based on a meta analysis of primary valuation studies in the Nordic countries. The analyses are carried out for the 108 catchments included the River Basin Management Plans for Denmark.

On the cost side, the reduction target of 13,000 tN has been set in order to reach good ecological status in 2027. The national costs vary from 600 to 1100 million DKK depending on the potentials and the measures used. The highest costs are where the reduction requirements are the largest.

The benefit estimates are based on a meta function. The meta function has been tested at it shows that the transfer-errors are within the bounds of what is considered acceptable for this type of benefit transfer. The average transfer error is 13.7 % with a median of 0.7 %. The benefit results show significant variations across catchments; accordingly, willingness to pay for good water quality varies across households. Variations in aggregate willingness to pay across catchments is also attributed to the variation in number of households across catchments. The average WTP was 1313 DKK per household. Further analyses will show the cost/benefit ratio in the different catchments which will be presented.

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The overestimated costs of fertilizer reduction – Time for new nitrogen fertilizer application heuristics

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The optimal use of nitrogen (N) fertilizer is on debate for more than 100 years. In the middle for the 19th century Justus von Liebig found that mineral nutrients are essential for plant growth and stated the Law of the Minimum which is widely interpreted as the foundation for proportional yield response of crops to the supply of fertilizer. Later Eilhard Alfred Mitscherlich found that crop yield response to fertilizer is diminishing resulting in the Law of Diminishing Returns, which is widly used in economic theory. The concepts of linear response and the Law of Diminishing Returns are contradicting eachother and until today both concepts coexist, leaving farmers and advisors confused about the best model to apply. Economic optima and nitrogen fertilizer reduction costs deviate substantially for the different approaches, resulting in confusion and potential barriers for N fertilzer reduction in agriculture. In fact many heuristics for fertilizer applications are based on nutrient contents of the harvested crops, implying the concept of the need to substitute the mineral nutrients of the harvested crops taking into account “inevitable” losses of nutrients, which need to be substituted by fertilizer.

This paper reviews the implications of different yield response models based on data from field experiments in Brandenburg, Germany. Profit maximizing N rates were compared to recommended N fertilizer values and costs of reduced fertilizer levels were estimated over six years for different assumptions about the course of the response functions and different price assumptions. On average, recommended rates were higher than the economic optimal fertilizer rates. The paper concludes with an assessment of N reduction costs for a range of scenarios and pledges for a new approach to recommend N fertilizer rates to farmers, which takes into account increased uncertainty due to climate change and the economics of N fertilizer use.

Costs and benefits of synthetic nitrogen for global cereal production under the INMS Shared Socioeconomic Pathways

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Cereals are the most important global staple food and use more than half of global cropland and synthetic N fertilizer. Synthetic N could feed about half of the global population but also has massively increased loss of reactive N to water and air, causing a suite of impacts that offset the societal benefits of N fertilizers. To assess current and future benefits and costs of changing inputs of synthetic N, a new model was developed for the UNEP INMS project. This model (NBCalCer) quantifies long-term global yields (using generic N response curves with soil N status in steady state (Van Grinsven et al., 2022)) and N budgets (country/state level) for rainfed and irrigated wheat, maize, rice and barley (using potential and water limited yields obtained from GYGA (www.yieldgap.org)and N inputs based on IMAGE-GNM and IFA). Further the tool monetizes changes in yield and N surplus. NBCalCer was applied for base years (2010-2020, hereafter baseline) and results were validated. Next it was applied for contrasting scenarios for 2050 (Shared Socioeconomic Pathways; viz. SSP1, SSP2 and SSP5, with contrasting climate and N policies). Global use of synthetic N is projected to change from 50.9 TgN in baseline and in 2050 to 41.5 in SSP1, 38.6 in SSP2 and 90.9 TgN in SSP5, with grain yields of 2.8, 3.8, 4.1 and 4.4 billion tonnes, respectively. The contribution of this synthetic N to global cereal production in baseline (2.8 Gt) was estimated a 47%, ranging between 27% in Sub-Saharan Africa (SSA) region to 75% in Canada. The total Nloss in baseline is estimated at 41TgN (80% of synth N) and is projected to change to 31, 36 and 69 TgN in 2050 (74, 934 and 76% of synth N under SSP1, SSP2 and SSP5). The global ratio in base year of the economic benefit of synthetic N to increase grain production over its summed cost from purchase and the external cost of the Nloss ratio was 1.6 (ranging from 0.3 in Australia to close to 5 in SSA, India and Brazil). This benefit-cost ratio is expected to decrease in future SSPs. Given the concerns about food security, environmental quality and its interaction with biodiversity loss, human health and climate change, the new paradigm for global cereal production is producing sufficient food with minimum pollution. Our results indicate that achieving this goal would require a massive change in global use and regional allocation of synthetic N.

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Evidence-based Nitrogen Indexes for Sustainable Agro-food Systems

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Although reactive nitrogen (Nr) inputs are essential for agricultural and industrial production, a large proportion of the Nr inputs is lost to the environment and cascades through the atmosphere, aquatic and terrestrial ecosystems with multiple negative effects (Sutton et al, 2021). Nr pollution induced by the agro-food systems are the result of millions of diverse producers/products worldwide produced under vastly different climates, soils and agronomic management (Poore & Nemecek, 2018). To identify effective solutions under this heterogeneity, we present a methodological framework to build evidence-based nitrogen (N) indexes for agro-food systems at varying levels of detail and complexity. Our results confirm that there is high variation in Nr loss among both food products and producers/countries. For most major animal and crop products, 90th percentiles of Nr loss per kg food product impacts are more than three times greater than 10th percentiles for all loss pathways. This suggests substantial scope to reduce Nr loss through producers. The lowest Nr loss for the 11 livestock products exceeds those of vegetable substitutes, providing new evidence for the importance of dietary change for reducing food's Nr loss through consumption. This evidence-based N indexes for global food that can adequately capture the environmental impacts and social costs (ecosystem and human health) of Nr associated with production, and potentially can serve as an effective tool to communicate to consumers, producers and policymakers. We demonstrate how our N indexes can be used to, firstly, highlight regions, management practices, and food products as potential foci for mitigation; secondly, estimate the societal cost of N pollution; thirdly, establish N labelling and rating to guide consumers' selection of food products with lower Nr loss and to incentivize farmers to adopt more sustainable N management practices; and ultimately, to make global agro-food systems more sustainable, less polluting and more profitable.

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A novel ammonia treatment of barley to optimize rumen function and increase N efficiency in sheep

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Meeting the energy and nitrogen requirements of high-performing ruminants while avoiding digestive disturbances (i.e. rumen acidosis) is a key priority in ruminant nutrition. This study evaluated the effect of a cereal ammoniation treatment, in which barley grains are combined with urea and enzymes that catalyze the conversion of urea to ammonia to optimize rumen function. Twelve rumen cannulated sheep were randomly divided in two groups and fed a diet containing 60% of ammoniated barley (AMM), or conventional barley supplemented with urea (CTL) to study the impact on rumen fermentation, feed utilization and N metabolic efficiency. Ammoniated barley had higher total N content and effective rumen degradable N fraction than conventional barely. AMM sheep had a consistently higher rumen pH throughout the day (6.31 vs 6.03) and tended to have a lower post-prandial ammonia peak and higher acetate molar proportion (+5.1%) than CTL sheep. The rumen environment in AMM sheep favored the colonization and utilization of agro-industrial by-products (i.e. orange pulp) by the rumen microbes leading to a higher feed degradability. AMM sheep also had higher total tract apparent N digestibility (+21.7%) and urinary excretion of purine derivatives (+34%) suggesting higher N uptake and microbial protein synthesis than CTL sheep. The inclusion of ammoniated barley in ruminants' diet represents a valid strategy to maintain rumen pH within a physiological range and to improve N utilization by the rumen microbes which could have positive effects on animal´s health and productivity in intensive production systems. This cereal ammoniation process also accelerated the utilization of agro-industrial byproducts by rumen microbes, that are normally low in protein content. This, along with the improved used of non-protein N, could help to decrease the environmental impact of ruminant production. These findings are currently being evaluated under conventional farm conditions.

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Influence of feed intake pattern of lactating sows on the nitrogen efficiency

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In lactating sows, protein consumption and feed wastage have a great impact on pollutant gas emissions. Electronic feeders make the sow eating more efficiently thus reducing feed wastage and allow the evaluation of both their daily feed intake and feed intake pattern during lactation. The aim of the current work was to evaluate the nitrogen intake and its relationship with litter gain produced by lactating sows according to different feed intake patterns. A total of 100 sows were selected and their feed intake was characterized as recently described by Rodríguez et al. (2022). To sum up, four feeding curves were defined as high (H) and medium (M) feed intake during the periods 0-6 days and 7-28 days of lactation: 1-HH (35 sows), 2-MH (23 sows), 3-HM (23 sows), and 4-MM (17 sows). Two sows were discarded from the experiment due to their low total feed intake (TFI). Sows were fed with a commercial lactation diet containing 16.5% of crude protein (2.64% of nitrogen). The TFI and the total nitrogen intake (TNI) of sows was determined. Litters were weighed both at farrowing and at weaning, and the litter gain during lactation period was calculated. In addition, loss of backfat thickness (BFT) during lactation was measured. The efficiency of nitrogen ingestion into kilograms of litter produced per sow was calculated. Data were analysed by a general linear model procedure (GLM procedure of SAS software). The TFI decreased ($P<0.05$) from pattern 1-HH (223.8 kg), 2-MH (204.8 kg) and 3-HM (192.7 kg) to pattern 4-MM (176.8 kg) (2.69 kg SEM). Consequently, the TNI also decreased ($P<0.05$) from 6.02 kg to 5.54 kg, 5.24 kg, and 4.73 kg (0.061 kg SEM) as the pattern number increased. These sows in pattern 4-MM also showed a higher loss of BFT compared with pattern 1-HH and 2-MH ($P<0.05$). As a result, nitrogen efficiency was lower in sows with the lowest TFI, pattern 4-MM (0.057 kg/kg) than in patterns 1-HH and 2-MH (0.069 and 0.067 kg/kg, respectively), keeping pattern 3-HM in intermediate values (0.055 kg/kg) ($P<0.05$). According to the results of this work it can be concluded that, a higher nitrogen intake not necessarily implies an increase of sow production during lactation. However, the caloric deficit faced by sows with lower consumption should be also taken into account because it might affect their later productive life.

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N balance to update excretion and NH_3 emissions from fattening pig farms in Eastern Spain

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Abstract

N losses are a major concern in intensive livestock production, particularly in areas with a high livestock density. In Spain, the main livestock sectors are being regulated to consider environmental criteria. For pig farms, the Royal Decree 306/2020 describes some measures to achieve important reductions in ammonia (NH_3) and greenhouse gas (GHG) emissions for existing and new farms. Among others, this regulation requires farms to apply multiphase feeding systems to reduce N excreta in manure. In recent years, advances in nutrition, genetics and installations have allowed achieving a better efficiency. The amount of nitrogen excreted by the pigs depends on several factors, such as the amount and type of N ingested or the digestibility of the protein. The Ministry of Agriculture, Fisheries, Food and Environment of Spain estimates that 65% of the N ingested in pigs is excreted in slurries (Babot, 2017). This report estimates that N excretion in fattening pigs from 20 to 120 kg is around 10.6 kg N per animal place and year. This work evaluates the efficiency in the use of nitrogen and ammonia emissions in the current livestock production sector in Eastern Spain.

To quantify the average content of N excreted in the slurry from pig farms in the Valencian Community, data from 87 fattening farms have been analysed. Information related to productive periods, animal weights, feed consumption and composition, crude protein level, and animal weights, has been provided by the farmers. A nitrogen balance has been carried out following the official methodology used in the Spanish emission inventory (Babot, 2017). Following this methodology, total nitrogen excretion has been obtained, as well as the inorganic (ammoniacal) and organic components. Finally, NH_3 emissions from housing, storage, and field application have been obtained following the EMEP/EEA methodology (EMEP/EEA, 2019).

Results show an average value of 6.17 kg N/place·year excreted in slurries from the fattening farms analyzed. Values ranged from 4.29 to 9.21 kg N/place·year, depending on the farm inputs. These results show an average reduction of 42% of excreted N, respecting the value of Babot (2017). Due to the N content reduction from pig slurries, NH_3 emissions were reduced by 43% in the housing, storage, and field application stages. Additionally, results show that the amount of N available to crops was reduced by 30%. This confirms the increased efficiency in the use of nitrogen and the great potential to increase efficiency at farm level.

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Project EmiDaT – Ammonia emission rates from fattening pig housings with outdoor yard in Germany

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The social demand for more animal welfare in fattening pig farming can be taken into account by building housing systems with outdoor yards. However, the question arose as to how these stables are to be assessed regarding the level of their ammonia emission rates. Therefore, ammonia emission measurements were carried out in fattening piggeries with outdoor yard of practice farms.

Measurements were carried out at 8 locations in Germany over at least six measurement periods to map the weather conditions over a year. Two types of piggeries with outdoor yards at 4 locations each were selected: closed floor of the yard with bedding material (1) and slatted floor of the yard (2).

Ventilation rates and accordingly emission rates of the piggeries with outdoor yard were determined using the tracer gas ratio method. An artificial tracer (SF_6) was used according to Schrade (2009). The tracer gas is added at a constant volume flow in the yard floor area. Tracer gas concentrations in the air are measured by GC-ECD. Ammonia concentrations in the air are measured simultaneously and at the same location using FTIR.

No statistically significant differences were found in annual ammonia emission rates between the two types of piggeries with outdoor yards. The overall calculated ammonia emission rate in this study for fattening piggeries with outdoor yard is 2.6 kg NH_3-N per animal place and year (mean live weight over the fattening period: 67 kg).

Our calculated mean annual ammonia emission rates for piggery with outdoor yards are lower than the emission value of 3.0 kg NH_3-N per animal place and year for forced-ventilated barns with fully slatted floors currently used in Germany (VDI 2011) in state licensing practice.

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Lignite is a low-cost technology for reducing nitrogen loss and odour from litter in commercial broiler housing

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Intensive broiler farms are a known point source of nitrogen (N) pollution. Uric acid, which is deposited on litter in bird manure, is rapidly hydrolysed to urea and then ammonia, which can be volatilised and deposited in the surrounding environment. This can lead to increased soil acidity, eutrophication of waterways and a reduction in biodiversity. Bird housing is also a point source of odour, which can be a nuisance to neighbouring communities and lead to difficulty obtaining farm development approvals. Odour is largely generated by the microbial decomposition of organic material, which in Victoria and likely other peri-urban areas, is the principal reason for complaints in relation to chicken meat production. While other agricultural industries have moved further away from cities to address this issue, broiler farms must have ready access to breeder farms, processing plants, labour markets, electricity, and water, which limits their ability to relocate away from peri-urban fringes. Lignite is a low-cost brown coal, which is abundant in Victoria. It has a high adsorption capacity and rich microporosity and has been shown to significantly reduce N loss and NH_3 from broiler litter in an incubation experiment (Costello et al, 2021). However, its effectiveness in commercial broiler housing had not yet been investigated. Lignite was applied to litter in bird housing over 3 consecutive grow-out cycles at a commercial farm in Mornington, Victoria, Australia. A significant reduction in N loss, in-house NH_3 concentration, odour emissions and litter decomposition were observed. This research aims to reduce N pollution from broiler housing and increase economic opportunities for farms by reducing odour. By addressing key cost-benefit drivers that impede the adoption of sustainable agricultural practices, we aim to improve the potential for uptake of N pollution reducing technology.

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Assessing the cost of technologies reducing ammonia emissions for future BAT requirements for finishers in pig production in Denmark

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The ambition of EU's Clean Air Policy Package to achieve a 27% reduction in ammonia emissions by 2030 compared to 2005. The Danish ammonia emissions have already been reduced by 43% from 1990 to 2015, but further reductions are required towards 2030. The goal is to find the right technologies to ensure both a cost-efficient implementation of measures and that the costs are acceptable to the industry (not excessive costs). The focus in this analysis is on the general BAT requirements and not the site specific measures linked to Nature 2000 areas (Jacobsen et al., 2019).

A new analysis of technologies and technology combinations and costs has been carried out in order to establish a basis for future BAT requirements for ammonia emissions in livestock production in Denmark. The technologies analyzed for finishers include both stable types (share of solid floors) and technologies like cooling, air cleaning (chemical and biological), acidification and solid cover of slurry storages. The technologies are analyzed separately, but the effect and costs can then be combined based on a chain effect. The analyses cover four different sizes of production from a yearly production of 1.700 to 45.120 finishers per year.

A total of 270 combinations of the many potential combination possibilities of stable types in combination with one or more environmental technologies are included in the analysis, where an ammonia reduction is achieved. Using the old BAT level requirements with maximum costs of €1.14 per finisher and €13.4 per kg NH3-N, it is found, that few technologies can pass this test, as the costs of the technologies are higher in 2020 than in 2011. Only fixed cover of slurry tanks is cheaper than before, but this alone does not give the reduction required to fulfill the current BAT requirements. As expected, implementing the technologies is cheaper on large herd sizes than on small herd sizes, which is why the old BAT requirements where differentiated according to size of production. The cost of the measures per slaughter pig is, in several cases, twice as large per finisher for the smallest herd sizes compared to the largest. The cheapest technologies and combinations are tent covering and cooling (10W/m2).

The analysis indicates that in Denmark reducing ammonia emissions for slaughter pigs is more expensive than before. This is also the case for some of the other livestock categories, but not all. The analysis therefore help to get an updated estimation of costs, which can be used both nationally and in the international modelling of costs and measures at the EU level.

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Crop Improvement for Nitrogen Use Efficiency (NUE)

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Progress towards crop improvement for nitrogen use efficiency (NUE) has been slow due to the multiplicity of NUE definitions, poor characterization of the phenotype and genotype for NUE. The lack of low N-input screening of crop germplasm and ranking by NUE also delayed biological identification of genetic targets for improvement. The crops to be improved also vary by country, depending on their scale of production and fertilizer consumption, apart from the nature of fertilizer itself (ammonium, nitrate or urea). For example, rice followed by wheat account for over two-thirds of Indian urea consumption and genetic variability in the rice germplasm accounted about half of the observed differences in NUE, making it an ideal target crop. We ranked 21 Indica rice varieties based on N-responsive germination, identified contrasting varieties and validated them in the field: Early germinating or short duration varieties were least N-responsive with relatively lower yield and NUE, whereas the late germinating or long duration varieties were most N-responsive, with relatively higher yield and NUE. We used 3 pairs of contrasting rice varieties for lifelong phenotyping at low and normal levels (1.5 and 15 mM) of nitrate or urea in the greenhouse. Of the 25 parameters measured, only 20 were significantly N-responsive, out of which only 8 contributed significantly to NUE, constituting the NUE phenotype. They are, germination and flowering time, shoot/root length and vegetative biomass, apart from yield-related parameters. In order to characterize the genotype for NUE, baseline transcriptome data were generated on the genomewide N-response in Indica and Japonica varieties of rice using microarrays. Further, comparisons of nitrate or urea-responsive transcriptomes of contrasting rice varieties revealed some candidate genes/pathways involved in NUE. They were prioritized for validation using hierarchical shortlisting of candidate genes by combining phenotypic-association, quantitative trait loci and bioinformatics. Mutants or genome-edited rice lines are being developed for final validation and shortlisting of the genes that have the largest role in NUE for crop improvement. This approach could also be useful for NUE improvement in other crops.

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Combination of plant-based fertilisers and compost can replace farmyard manure for nitrogen fertilization, and builds soil fertility in organic vegetable production

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Intensive vegetable production relies on high nitrogen (N) fertilization. However, the availability of organically certified fertilisers is limited, and the use of fertilisers of conventional origin is restricted in organic production. Plant-based fertilisers can be produced on-farm in large quantity by growing green manures (Hefner et al., 2020), and composts are provided from waste recycling. The effects of the combination of plant-based fertilisers and compost on crop nitrogen availability and soil fertility is little studied. We hypothesized that fertilisation that combines plant-based sources such as green manures and compost can replace farmyard manures. The plant-based combination will provide sufficient nitrogen for crop growth, while improving soil fertility.

To test this hypothesis, we conducted a field trial over two years in cabbage and beetroot in Denmark on sandy loam and supported by a pot trial testing plant-based combinations of green manures and compost. The results were compared to similar trials from other European countries.

Results showed that potential nitrogen mineralization increased already in the second year of the field trial when plant-based combinations were compared to fertilization with farmyard manure. Crop nitrogen uptake was maintained without yield penalty. Soil mineral nitrogen in deep soil layers did not indicate an increased risk of nitrate leaching to the environment. The pot trial showed that there was an additive effect from the green manure and compost application on nitrogen availability and soil microbial enzyme activities indicating improved soil fertility. From a longer-term perspective, the plant-based combinations of green manures and compost have the potential to increase both nitrogen availability and soil fertility due to the high inputs of organic matter compared to farmyard fertilisation.

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Nitrogenous sources and tillage depths determine NUE in wheat crop

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Nitrogen (N) is the most important essential nutrient for plant growth and productivity and plays a key role for sustainable agriculture. There are many factors which are responsible for N losses and decreasing nitrogen use efficiency (NUE), including nitrogenous sources as well as cultural practices. Along with NUE, the contribution of N sources and tillage practices towards greenhouse gases (GHGs) emissions and climate change still needs to be elucidated. The objectives of our study were to identify the optimal combination of tillage and N fertilizer source to enhance crop profitability via increased NUE and to reduce N losses including GHGs emissions. A field experiment was conducted at research area of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad-Pakistan (31.4391° N, 73.0700° E). Two nitrogen sources (Urea and Calcium ammonium nitrate, CAN) at the rate of 160 Kg N ha^{-1} for wheat were applied in 3 splits and two tillage depths (conventional tillage 15 cm and deep tillage 30 cm) were maintained along with control where no N was applied. Each treatment was replicated four times and 30 m^2 plot size was maintained. The results of the study showed that NH_3 volatilization were higher in urea as compared to control and CAN regardless of tillage depths and peak values were after fertilization events. While in CO_2 effluxes, under conventional tillage, sources have no significant impacts on emissions but interestingly, under deep tillage practice, there were low CO_2 emissions when urea was applied compared with CAN. The plant biomass increased in fertilized plots and was maximum when CAN fertilizer was applied under deep tillage. The NUE under conventional tillage was more in Urea as compared to CAN while NUE was similar for both N sources under deep tillage. Under conventional tillage, NO_3 leaching was pronounced with the application of urea while it was opposite in deep tillage where NO_3 contents at different soil depths were higher with the application of CAN fertilizer. While considering impacts of N sources and tillage depths on soil health, we found that soil microbial biomass carbon significantly increased with CAN fertilizer application for both tillage practices. Similarly, extracellular enzyme activities such as β-glucosidase, acid phosphatase and leucine aminopeptidase activities were higher with CAN fertilizer application. Higher activities of chitinase in Urea indicated microbial turnover in soil. We concluded that use of CAN fertilizer has positive impacts including low gases emissions, improved crop growth and efficient microbial activities compared with urea, especially in deep tillage practices.

The Effect of Nitrogen Fertiliser Type on Milling Wheat Yield and Crop Nitrogen Use Efficiency, Findings from a 3-Year UK Study

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Nitrification inhibitors, urease inhibitors and controlled release fertilisers have the potential to increase nitrogen (N) efficiency and reduce the environmental footprint of agricultural systems. It is well documented that ammonia (NH_3) emissions from urea fertiliser are greater (than ammonia nitrate (AN) and that the addition of the urease inhibitor N-(n-butyl) thiophosphoric triamide (nBPTP) can be effective at reducing emissions (Chadwick, et al. 2005). Furthermore, the addition of nBTPT, can improve crop nitrogen use-efficiency (NUE) of urea to match the performance of AN (Dampney, et al., (2006). Whilst the efficacy of urea +nBTPT is well studied, few field experiments have been carried out assessing the agronomic performance of other enhanced efficiency fertiliser products compared to AN.

A 3-year study (2019-2021) was carried out in Nottinghamshire England. In each year, nitrogen response experiments were set up on milling wheat in a randomised, replicated (3 times) design; with 7 different nitrogen fertiliser products (1. AN, 2. Urea, 3. urea ammonium nitrate (UAN), 4. UAN + urease inhibitors nBTPT & N-(n-propyl) thiophosphoric triamide (NPPT), 5. Urea +urease inhibitor nBTPT, 6. Polymer coated urea, 7. Urea + urease (2-NPT) & nitrification (MPA) inhibitors) applied at 7 rates (0, 60, 120, 180, 240, 300 & 360 kg N/ha). Grain yields were measured on each plot using a plot combine and representative grain samples were analysed for total dry matter and N %. Multiple regression was used to fit response curves to yield, grain N-offtake (kg N/ha) and grain protein (%) data, for each of the fertiliser products. Economic optimum nitrogen fertiliser rates and yield at N-optimum was calculated assuming a breakeven ratio of 5:1. Mean nitrogen recovery (across the 6 N rates) was calculated for each fertiliser product as: mean net nitrogen uptake (minus 0N control) as a percentage of total nitrogen fertiliser applied.

In all years, winter wheat yields responded well to N-fertiliser application. The optimum N-fertiliser rate varied between years reflecting site and climatic differences. In all years, there was no significant difference in yield response between the fertiliser products. However, in each of the 3 years the optimum N-rate for AN (3-year mean = 193 kg N/ha) was lower than for all other urea-based products (3 year mean ranged between 214 kg N/ha and 246 kg N/ha); whilst yield at N-optimum was similar for all the fertiliser products. Overall, N optima for the urea-based fertiliser products were 20 to 50 kg N/ha greater than for AN. The mean NUE of AN was between 12% and 5% greater than the urea-based fertiliser products.

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Estimation of changes in soil organic N stocks is crucial to determine the fate of surplus N in intensively managed cropping systems

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The European Nitrogen Expert Panel (EUNEP[1]) has proposed N surplus as an indicator of the potential N losses from agriculture to the environment. The use of N surplus as an indicator for N losses essentially rely on the assumption that the soil organic N (SON) stocks remain unchanged; however, this assumption may not hold on farms developing intensive production, ultimately questioning the adequacy of its use in a wider context. The adequacy of N surplus as an indicator can be scrutinized by estimating actual N losses and SON stock changes over time through experimental and/or modelling (i.e. using the Daisy model[2]) approaches. This model based study was carried out with Daisy[2] to estimate N balance components including N surplus, total N loss (N escaping to the atmosphere and hydrosphere) and annual changes in soil organic N stocks within the root zone for a large number of realistic scenarios. The scenarios were based on diverse crop rotations, texture-based soil types, soil organic matter levels in the A horizon, cropping pre-histories varying in C input and the proportion of N supplied in manure vs. mineral N. The results, averaged over 24-year simulation period, indicated large variation in SON stock changes (-48 to +8 kg/ha/y in the 0-100 cm soil profile) under different crop rotations. Addition of grass-clover ley in the rotation had a positive effect on SON as compared to spring-cereal dominant rotations, which lead to depletion of stocks. Generally, the SON stocks tended to increase, or be depleted with a lower rate under rotations containing grass-clover ley, low C input cropping history (spring barley), coarse sand, low initial SOM and higher proportion of N application as manure. Expectedly, the relations between N surplus and N loss were strong for spring cereal dominated rotations (R^2 = 0.67 – 0.93). In contrast, N surplus vs. SON stock change relations were relatively strong for rotations with grass-clover ley in the sequence (R^2 = 0.21 – 0.90) as compared to other rotations (R^2 = 0.13 – 0.75). We estimated average error for N losses (calculated as the difference between the simulated N losses and N losses estimated by considering entire N surplus as N loss), which ranged from -45% (underestimation) for maize monoculture to +50% (overestimation) for continuous grass-clover ley. These results confirmed that the assumption that SON stocks remain unchanged is questionable, and highlighted the importance of including SON stock changes in N-balance sheet. The findings imply that N surplus would be an accurate indicator for N losses only under conditions where a steady state equilibrium has been reached. However, using the N surplus indictor without accounting for the changes in SON stocks under conditions where stocks change, may result in under- or overestimation of potential N losses, and ultimately lead to biased conclusions.

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Assessment of nitrogen management practices for intensive irrigated agriculture sustainability

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In intensive agricultural systems, irrigation and nitrogen (N) fertilizer are the most important factors that influence crop production and N losses. This work aimed to assess the N management practices using the calibrated and validated Decision Support System for Agro-technology Transfer (DSSAT) model for the main cultivated crops (Malik et al. 2018; Malik and Dechmi, 2019) in La Violada Irrigation District (VID, Northeast Spain) to enhance irrigation return flows quality. In total, 59 farmers' field plots were selected from 2014 to 2017 crop seasons distributed in different soil types in the VID in order to assess the current and optimum N fertilization and the combined irrigation and N fertilization management practices. Considering the whole VID cultivated crop area in each soil type and comparing with the current N fertilization, results showed that the optimum N management could reduce the NO_3–N leaching below root zone by 51 % and the residual NO_3–N in soil by 58 %. These reductions could be improved further by 35 % and 3 %, respectively, under the combined N fertilization and irrigation optimum management (irrigation dose adjusted to the crop water requirements). Moreover, the adjusted irrigation and recommended N fertilization could reduce N_2O–N emissions by 60 %, the triple than under the recommended N fertilization alone. The more vulnerable soils for NO_3–N leaching found were shallow and/or very permeable soils. As for the impact of individual crops, both long and short season maize were identified as the most polluting crops (84 % of total N leached) due to the heavy fertilization applied by the local farmers that exceed crop requirements by more than 50 %. This study supports the importance to incentivize farmers to adjust their N fertilizer and irrigation practices to crop requirement and soil properties to ensure production while improving environmental sustainability.

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Influence of different N sources and tillage depth on NUE and soil microbial activity in wheat crop

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Nitrogenous fertilizers are critical for crop production but non-judicious use with poor management enhances the reactive nitrogen (Nr) emissions decreasing nitrogen use efficiency (NUE) and crop profitability. Comprehensive nutrient management practices are required to improve soil health and yield, simultaneously, for sustaining crop production. A field study was designed with seven treatments (Conventional Tillage depth (CTD) with no N (control), CTD with 100% recommended N as urea, CTD with 75% recommended N as urea, CTD with 125% recommended N as urea, CTD with 100% recommended N as animal manure, CTD with 100% recommended N as calcium ammonium nitrate (CAN), deep tillage (DT) with 100% recommended N as urea. Each treatment was replicated four times by maintaining 30 m^2 plot size. The agronomic and yield parameters were determined at maturity of crop. The agronomic parameters such as plant height and number of the plants m^{-2} were non-significant, plant biomass increased in N fertilized treatments and were maximum in CTD and DT with 100% recommended urea N as compared to control and other treatments. The yield m^{-2} were maximum in CTD with 125% N fertilizer as compared to control and non-significant among other treatments. The shoot and husk N concentration increased in N added treatments being maximum in CTD with 100% recommended N and CTD with 100% N as CAN as compared to control and other treatments. The grains and soil N increased maximum in CTD with 125% N fertilizer. The soil nitrate was maximum in CTD with 100% N fertilizer and CTD with 125% N fertilizer at 15-30 cm depth as compared to other depths (0-15 and 30-45cm depths) and other treatments. The NUE was maximum in CTD with 125% N and was in order CTD with 125% urea N ≥ CTD with 100% urea N ≥ DT with 100% urea N ≥ CTD with 100% CAN N ≥ CTD with 100% N as animal manure > CTD with 75% urea N. Soil organic carbon increased in CTD with 100% animal manure N in top and sub soil. Soil microbial biomass carbon was decreased in 100% and 125% N treatments at both depths and increased in CTD 75%, CTD with animal manure and deep tillage with 100% recommended N treatments at 0-15cm depth. Activities of extracellular enzymes showed mixed trend as β-glucosidase activity was significantly more except CTD with 100% and 125% N. Chitinase activity decreased in CTD 75% N fertilizer and increased in DT urea treatment. Acid phosphatase activity was non-significant among all treatments and Leucine Aminopeptidase activity decreased in CTD 125%, CTD with animal manure and CTD with CAN. The agronomic and yield parameters of crop as well as NUE increased by inorganic N high doses while soil health parameters enhanced by organic N addition. The combination of inorganic and organic N sources should be considered in N management both for soil health as well to maximize crop production.

Keywords: Animal manure, N fertilizer rate, Soil enzymes, NUE

A comprehensive review on the fertilizer subsidy policy and its impact on nitrogen fertilizer use in Sri Lanka

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Sri Lanka provides an interesting case to study the influence a fertilizer subsidy policy could have in shaping the natural, socio-political and economic landscape of an agrarian nation. The fertilizer subsidy scheme for rice (the staple food in Sri Lanka), which was initiated in 1951, came to an end with the recent move of the incumbent government to ban importation of all forms of synthetic fertilizer in 2021. This abrupt policy decision created a public unrest which dramatically grew into a political turmoil. The government was compelled to lift the ban but the subsidy scheme still remains suspended despite the small farmers daunting requests to receive urea at an affordable price. The subsidy scheme, over its long history of 70 years, turned Nitrogen (N_r) fertilizer into one of the most politically sensitive commodities in Sri Lanka. As per the historical records, there had been a strong resistance from the small farmers to adopt synthetic fertilizer, even with lucrative price incentives provided by the subsidy in its inception. Eventually, over the next few decades, the fertilizer subsidy program transformed synthetic N_r fertilizer into an indispensable input in rice production and gained prominence as a customary right of the small farmers. It is unarguable that the fertilizer subsidy scheme was instrumental in helping Sri Lanka to attain self-sufficiency in rice by the year 2009. However, the subsidy is also blamed for inducing N_r misuse and inefficiencies in almost all the farming systems and exerting a significant cost on environment and human health in Sri Lanka. Further, heavily subsidized N_r fertilizer grew into a national burden as the country had to entirely depend on overseas markets for synthetic fertilizer. The evidence shows that the fertilizer subsidy scheme has evolved on a path shaped by competing interests originated out of global pressures, national goals as well as political motives. The scheme, has undergone a number of distinctive reforms ranging from suspension of the subsidy to free distribution of urea. The evidence shows that the drastic and improper reforms introduced to the subsidy program have even resulted at times in public unrest, food shortages as well as mis-consumption of fertilizer. This paper, with reference to historical narratives and data, critically elaborates the impact of the fertilizer subsidy scheme in shaping the trajectory of nitrogen use by the smallholder rice farmers in Sri Lanka. The paper also discusses how the feedback from socio-political context influenced the fertilizer subsidy scheme to undergo various reforms with competing interests. This study has policy implications for Sri Lanka as well as other agrarian nations to consider in determining strategies to promote sustainable consumption of N_r in smallholder farming systems.

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Best practices in promoting and implementing sustainable nitrogen management policies

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20 years ago, Romania was on a clear pathway towards EU accession. In terms of policies and public administration, this triggered reforms, especially on environment protection. While transposing EU legislation was relatively a simple process, the reforms at farm level are requiring consistent and efficient long-term investments and behavioral changes national programmes. Starting with pilot investments and gradually fine-tuning and scaling-up the approach, Romania developed and implemented programmes addressing especially the small and medium-size farms. Ensuring the sustainability of these interventions was a concerned considered from the beginning of the programmes design. Various funds sources were considered, but EU funds are currently taking the lead on targeted reforms envisaged to be implemented during 2023 - 2027.

Furthermore, a raising interest in efficient use of N appeared due to the recent Global concerns on food security and because of the 3-fold increase of fertilizers costs. Thus, it suddenly became more reasonable and political acceptable allocating public funds and administrative energies in implementing public policies on sustainable N management, but what kind of interventions will be most suitable? In the context of Romania types of farming, a mix of communal platforms, farmer-led knowledge transfer networks and awareness campaigns proved efficient means. This may be a policy answer for many other small-scale farming dominated agricultural systems.

At international level, under INMS and some UN countries initiatives, a set of international agreements are promoting more ambitious national policies. The UNEA – 4 resolution and Colombo Declaration on Sustainable Nitrogen Management, the Farm-to-Fork Strategy and the recent adopted UNEA - 5 Resolution on N management introduced targets for the reduction on N waste gave a clear direction of future policies: N should be more efficient used / air and water pollution should be prevented and reduced. This calls for new types of guidelines, training materials and awareness campaigns, as well consistent investments programmes. Examples of best practices for international knowledge transfer are part of the solution.

Oceania: A global region with diverse nitrogen issues, policy responses and future challenges.

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Oceania is home to 42 million people in 14 countries, across more than 1000 islands in Australasia, Melanesia, Micronesia and Polynesia. The largest countries by land area include Australia, Papua New Guinea and New Zealand, which also make up 93% of Oceania's population. Oceania spans the equator to 48° South and includes highly diverse terrestrial ecosystems and some of the world's most extensive and diverse coral reefs. The region encompasses countries with disparate economic development and farming systems that range from subsistence to large-scale and globally important food and fibre production.

Nitrogen is a major contributor to agricultural production in Oceania. Inputs range from insufficient to excessive, reflecting the diverse socio-economic conditions, climates, crop types and production systems as well as regional policy settings. In Australia and New Zealand, numerous scientists, policy experts and industry stakeholders work on nitrogen-related issues across a broad range of industries and regions. There is less information on nitrogen use and interactions in countries that include Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.

While the role of nitrogen in farming enterprises and its impacts on natural ecosystems and GHG emissions is well recognised, motivations and ability to increase nitrogen efficiency in systems receiving excessive nitrogen are often inadequate. Conversely, where nitrogen input is limited, food security and soil fertility (i.e. declining organic matter) are challenged. Improving nitrogen management in Oceania is therefore a complex task. It demands supporting the productivity of diverse agricultural systems and ensuring food security, while protecting fragile terrestrial and aquatic ecosystems including oceanic ecosystems that include coral reefs and seagrass meadows that are sensitive to N pollution.

In this paper we will present diverse regional and industry nitrogen issues and policy responses in Oceania as they affect reactive nitrogen in the biosphere, including increasing nitrogen fertiliser use and intensive animal production systems. We argue that an essential first step is to quantify nitrogen budgets and nitrogen use efficiencies across applications and scales, and to develop and share solutions that enable the sustainable use of nitrogen. Additionally, we will explore some implications of the ammonia (hydrogen) economy for energy production, and the potential implications for the nitrogen cycle, nitrogen accounting and the wider ecosystem.

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Strategies and policies for reducing nitrogen wastes in the United States

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Assessments of nitrogen budgets for the United States conducted within the last 15 years provide reasonably good estimates for national sources and sinks of N. About half of all inputs are from Haber-Bosch fertilizers and crop biological fixation. About one-third is used in products from agriculture and industry and about two-thirds is lost to the environment (Houlton et al. 2013). Emissions of NOx from energy and transportation sectors have declined significantly since the 1990s as a consequence of amendments to the Clean Air Act enforced by the Environmental Protection Agency (EPA). Problems with eutrophication of water bodies and nitrate levels in drinking water have become more common in some regions. The EPA requires states to calculate Total Maximum Daily Loads (TMDLs) and to develop local plans to achieve them in impaired watersheds, but progress has been spotty at best. Fertilizer use has been relatively flat since 1995, while crop production has increased, resulting in modest increases in N use efficiency (NUE) in croplands, due to a combination of improved technologies and voluntary actions by federal, state, and local governments, the private sector, NGOs, and universities to promote the “4Rs” of nutrient management. In contrast, NH_3 emissions from manure management and animal production systems are mostly unregulated and are increasing.

At present, there are no plans to initiate the development of a National Action Plan (NAP) to reduce N wastes in the U.S. The EPA and the U.S. Department of Agriculture (USDA) have several initiatives on specific forms of pollution and nutrient management, but we are unaware of any cross-sectoral planning or coordination on N, such as minimizing risks of pollution swapping. Assessing NUE for the broader agri-food system is occurring mostly in academia. A directive for EPA and USDA to develop an integrated NAP focused on N wastes would likely need to come from high levels of the government. The White House recently announce a plan to issue a Global Fertilizer Challenge to improve fertilizer use efficiency in response to fertilizer shortages and price increases, as well as concerns about global food security, provoked by the war in Ukraine (White House, 2022). Likewise, increased ambition by the Biden administration to address climate change, such as promoting a global methane pledge, may bring additional interest to mitigating N_2O emissions from both agricultural and industrial sectors. The 2023 Farm Bill also offers opportunities to increase incentives for improved NUE in crop, animal, and food systems. However, connecting these encouraging prospects in an integrated NAP on N wastes remains a major challenge without a clear pathway.

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Reactive-N in South Asia – Strategies for Sustainability and Reducing Waste

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South Asia is a critical region for the anthropogenic effects of the global N cycle and deteriorating impacts on ecosystem services. Nitrogenous fertilizer is a major agricultural input into the cereal-based cropping systems across most of the region. South Asia is the second largest fertilizer consuming region in the World (FAO, 2016) with consequent pollution especially related to fertilizer overuse. The region contains many Nr hotspots showing high absolute quantities and growth rates relative to global means. Nr emissions as NH_3 and N_2O have roughly doubled since the 1980s. For NH_3 and N_2O the agriculture sector (including animal husbandry) is the main emission source. Although use of N fertilizer has resulted in a steady increase in crop yields in the region, indiscriminate use has brought extensive negative impacts on ecosystems and environment. In South Asia, recovery efficiency of N applied through fertilizer and manure has declined from 94.4% in 1970 to 61.2% in 2017. The scenario has prompted overzealous farmers applying in excess of nitrogenous fertilizers, leading to economic loss as well as leakage of reactive-N to the environment. Different country governments have introduced administrative actions and policies to manage the wastage of fertilizer-N and followed up with UNEA-5 resolution to reduce N-fertilizer wastage by 50% before 2030. Attention is paid on the following key areas for reducing leakage of reactive N-wastes including (a) Improving the performance of N-fertilizers, (b) Improved management of biological N fixation (c) Improving performance of livestock production, (d) Improved use and proper cycling of organic-N resources, (e) Reduce food wastage and balanced meat and dairy consumption and (f) Introduce measures to improve landscape resilience to N pollution. However, several barriers are required to be removed for effective minimization of N-wastage by introducing new policy initiatives. Halving N waste may reduce gaseous N- emission by 19% by 2030 & 30% by 2050.

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The Dutch region-specific nitrogen policy approach: addressing nitrogen to support biodiversity

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First the evolution of the Dutch policy approach till now with respect to nitrogen as applied to agriculture will be discussed (Daatselaar, 2022). Recently a new so-called region-specific approach has been launched which combines generic measures and region-specific approaches. A very ambitious set of targets has been specified and one of these targets is to bring about 75 percent of the Natura 2000 areas below their critical deposition values for nitrogen. Another target is to increase biodiversity. So far the policymakers are less clear about how these targets have to be achieved, although several actions (low protein feeds, low emission stables, low emission manure application techniques, etc.) have been suggested, a large budget (25 billion euro) has been devoted to solve the problem (including budget for large scale farm buy-outs) and measures have been announced to create a sufficient perspective for farmers.

Further it will be discussed how feasible the policy targets are, and which instruments are needed to achieve the objectives. Here two aspects will be further highlighted: i) which instruments fit well in that they contribute to the advocated integral policy approach, which alongside nitrogen also addresses other policy challenges such as climate, water, and biodiversity; and ii) which instruments, or combination of instruments are relevant when striving for a cost-effective solution. Insights from empirical studies (e.g. PBL, 2020) will be used to argue that the least cost-principle needs more attention in the Dutch policy debate.

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Ammonia emission measurements from dairy housing and wastewater treatment plants using an inverse dispersion method

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Ammonia emissions produce negative human health and environmental impacts by affecting air quality, soil, water, and biodiversity. Largest emissions stem from the agricultural sector and especially in countries with high livestock density such as Switzerland, emissions from animal housing, as well as waste and manure storage and application are dominant. Measuring total emissions of multiple heterogenous sources from buildings and open structures such as farms and waste treatment facilities can be challenging. Previous studies have shown that quantifying net fluxes at this scale can be achieved using an inverse dispersion method, which combines concentration measurements up- and downwind of the structures with backward Lagrangian stochastic modelling to calculate the emissions from a defined source area. Conditions in Switzerland including complex topography and smaller emission sources deviate from the ideal micrometeorological requirements for this method. Here we present results from several successful applications of ammonia (together with methane, not presented here) emission measurements from cattle housing using miniDOAS and inverse dispersion methods and the first such measurements from wastewater treatment plants in Switzerland. Results were compared with a reference inhouse tracer ratio method conducted at the cattle housing and were within the uncertainty range of <10%.

The inverse dispersion method may be increasingly helpful not just in determining emission factors from complex sources and structures, but especially when applying and assessing emission reduction measures on farms and waste storage and processing facilities. Since ammonia emissions occur in conditions counter to those required to produce methane and nitrous oxide emissions, both potent greenhouse gases, this creates a tradeoff between mitigation measures to reduce emissions from one gas which may increase emissions from another. Therefore, it is vital to quantify ammonia emissions concurrently with at least one of the two other gases to assess the net impacts of the mitigation measures which can be done using this method.

Ammonia emission and landscape fluxes near a cattle feedlot in Victoria, Australia

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Concentrated animal feeding operations (CAFOs) are ammonia (NH_3) emission hotspots which can contribute nitrogen (N) to the surrounding landscape through dry deposition. This presentation will report a summer field campaign conducted at a cattle feedlot in south-eastern Australia in February 2020. Emission rates of NH_3 from the feedlot were measured with an inverse dispersion modelling (IDM) technique, based on gas concentrations measured inside the feedlot with open-path lasers. Landscape NH_3 fluxes adjacent to the feedlot were measured with a flux-gradient technique using open-path Fourier transform infrared (OP-FTIR) sensors to measure vertical gas concentration gradients 110 and 220 m from the feedlot boundary. Results showed a total feedlot emission factor of 180.8 g NH_3 head^{-1} d^{-1}, corresponding to a loss of 65% of the feed N. When upwind of the feedlot, the two sites showed upward fluxes (surface emissions) with a daily mean of 0.05 and 0.06 μg NH_3 m^{-2} s^{-1} at the two distances. This corresponds to net NH_3 emissions equivalent to 43.2 and 51.8 g NH_3 ha^{-1} d^{-1}. When downwind of the feedlot, the two measurement sites showed downward fluxes (surface deposition) with a daily mean value of -1.16 and -0.69 μg NH_3 m^{-2} s^{-1} at 110 and 220 m from the feedlot. This corresponds to a net NH_3 deposition equivalent to 1.0 and 0.6 kg NH_3 ha^{-1} d^{-1}. During the campaign, the amount of NH_3 deposited totaled around 9800 kg NH_3 within a 5×5 km deposition grid centered on the feedlot, accounting for 11% of the total NH_3 emission from the feedlot. Such measurements provide reliable data for NH_3 inventory, model simulation of the NH_3 transport from the feedlot, and contribute to development of sustainable N management strategies for the surrounding agroecosystems.

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Modelling and mitigating nitrogen emissions from key European dairy production systems

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European dairy production systems (DPS) face stricter and increasingly binding environmental protection requirements where context-specific actions are needed. Evaluating the environmental impacts of DPS is a crucial step for applying adapted approaches to ensure and promote sustainability. Whole-farm models are presented as useful tools for assessing these impacts as they encompass individual farm processes through an integrated system approach. In this context, the Sustainable and Integrated Management Systems for Dairy Production ($SIMS_{DAIRY}$) evaluates the effect of different farm characteristics and bioclimatic conditions on environmental indicators such as the nitrogen footprint (NF). This study aims to model the nitrogen emissions of six key DPS in Europe and assess the effect of selected mitigation options to reduce ammonia (NH_3) emissions. Productivity, diet composition, land use, manure management and fertilization management were the main modeling inputs. Heterogeneous geographic distribution of the scenarios was considered to evaluate the effects of a wide range of climatic conditions. The results show a large variability in the intensity of NF analyzed, averaging 9.8 gN l milk-1 and ranging from 16.1 to 6.9 gN l milk^{-1}. NH_3 and nitrate (NO_3) emissions represent the highest contributors to the NF in all scenarios analyzed. Manure storage was identified as one of the major hotspots for NH_3 emissions (33% of the NF on average) in those scenarios with low efficient practices. As for NO_3, those scenarios with higher application rates of mineral fertilizers (urea) present higher emissions of this gas, averaging 61% of the NF. Preliminary results show how high-efficiency covers reduce NH_3 emissions in those scenarios with high emissions from manure management. Furthermore, substituting urea with alternative fertilizers such as ammonium nitrate resulted in significant reductions in the NF. This study shows how the application of adapted measures in different DPS leads to a substantial reduction in nitrogen emissions at the farm scale. In this way, this study cooperates in making informed decisions when mitigating the negative environmental impacts of DPS.

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A newly developed model for quantification of nutrient flows and losses along dairy manure management chains with different complexity

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Nitrogen (N) loss from manure management chains (MMCs) of dairy farms are substantial and variable. The complexity of MMCs varies dependent on the method of collection and the number of subsequent storage and processing technologies used. We developed a modular approach that quantifies flows and losses of total ammoniacal N (TAN) and organic N along MMCs with different complexity. This approach allows integrating any number and sequence of manure management facilities to simulate MMCs in on-farm settings. Nitrogen flows and losses from nine published case studies were quantified using established emission factors of different N species for various manure management facilities. Comparisons between simulated and reported N losses of nine published case studies showed deviations ranging from 0.05% to 40% for the whole MMCs. The largest deviations were caused by uncertainty about emission factors for open lots, grazing lands and anaerobic lagoons. By revising the reported emission factors, deviations in N losses can be reduced to less than 10%. Simulated N losses were within the range of estimates obtained from the application of the present IPCC Tier2/Tier 3 methodology, which further validates the reliability of estimates using the modular approach. Further, we extended this approach and developed a model (FarmM3) to quantify flows of different manure constituents along MMCs. This FarmM3 model can track flows of manure organic matter (OM), carbon (C), nitrogen (N), phosphorus (P) and potassium (K) and quantify gaseous emissions from various MMCs by integrating established emission factors, loss coefficients and performance parameters. A sensitivity analysis can be performed to identify the most important input parameters determining losses of manure constituents in complex MMCs. This model can also support to design and optimize dairy manure management strategies at farm level by evaluating trade-offs among degradation of organic matter, nutrient losses and gaseous emissions of various MMCs. In conclusion, the FarmM3 model based on modular concepts is highly flexible and adaptable and can be used to assist dairy farmers in optimizing manure management strategies.

Advantages of a well-referenced flow-chart of manure management to spatialize nitrogen pressure and ammonia emissions: the case of Brittany (France)

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Nitrogen loss leads to air, soil, and water pollution, loss of biodiversity, and a wide range of climate-change impacts. Therefore, accurately assessing the sources and flow of nitrogen from the agriculture sector is still a challenge. In Brittany (France), mitigation measures have been applied for more than 30 years to reduce high nitrate concentrations in the surface water due to intensive agriculture. We observed substantial improvements, but the regional mean concentration in nitrate seems to have reached a plateau (around 36 mg/l) with diverse situations for five years. The public stakeholders are thinking about additional measures to tackle some specific water issues (algal blooms, drinking water directive, nitrate directive, European Water Framework Directive), focusing on spatialized actions according to the characteristics of each catchment (nitrogen and cultural pressure, hydrological characteristics, nitrate concentration in surface water). The form (solid manure, slurry, droppings) and the place (housing, pasture, outdoor run) the manure is produced strongly impact the nitrogen cycle and consequently the nitrogen losses. Therefore, it is fundamental to characterize the different nitrogen flows to select the best available mitigation techniques. Since 2014, the public stakeholders have imposed a Nitrogen Flow Declaration (DFA) for all the farmers in Brittany. This DFA allows quantifying the nitrogen applied to agricultural soils each year. The DFA considers national default nitrogen values for the different animal categories modulated according to specific ways of rearing. The administration's display of pressures from the DFA only targets the total, the mineral, and the organic nitrogen pressures. In 2018, these pressures were 177.0, 67.6, and 109.4 kg N/ha UUA, respectively. Further calculations of data allow identifying the cattle herd as the primary source of manure nitrogen (71.2 kg N/ha UUA), followed by the pig herd (27.1 kg N/ha UUA) and the poultry herd (10.4 kg N/ha UUA). Various alternative managements to spreading (treatment and exportation) make it possible to avoid spreading 12.1 kg N/ha UUA from livestock manure. The manure treatment eliminates around 4.0 kg N/ha UUA while about 5 kg N/ha were exported out of Brittany (mainly dried droppings from laying hens). The spatial distribution of the data over 66 catchments highlights the variability of the pressure in connection with the intensity of the animal production, the dominant production, and the type of manure produced. This impacts the ammonia emissions (estimated at 37.8 kg N/ha for the region) ranging from 17.0 to 85.2 kg N/ha UUA. These results confirm what we already know about the impact of the hot spots of animal production. However, the results will be helpful to stakeholders in the case of the choice of spatialized mitigation techniques.

Analysis of Nitrogen balances and Nitrogen Use Efficiency on farm level of the German agricultural sector – implications for policy design

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Nitrogen (N) use is a key environmental issue in agriculture, as losses of reactive N compounds threaten biodiversity, climate, and human health (Sutton & Bleeker 2013). The utilization of N as an essential macronutrient must become more efficient in order to mitigate the negative externalities of food production and to achieve the ambitious (inter-)national climate, environmental and sustainability goals concurrently. The Nitrogen Use Efficiency (NUE) in an appropriate indicator for assessing N utilization in farm systems, and can be estimated from the same parameters as the N balance. Thus, the aim of the present work is to quantify the level of NUE for different farm types in Germany and to identify determinants of on-farm N indicators. For that, we use data of the German Farm Accountancy Data Network (FADN), covering around 6,000 farms with comprehensive annual information on farm structure and yields, and representing the German agricultural sector. For calculating the NUE on farm level for six farm types according to EU farm typology, the relevant input and output parameters as three-years mean are considered based on Löw et al. (2021) and national legislation. Further, two explanatory models are developed to identify linkages between the N indicators investigated and farm structural (e.g., farm type, farm size, and fertilization intensity), regional (e.g., soil fertility, altitude, and soil-climate-areas), and socio-economic (e.g., age, operating profit, and education level) attributes. The MM-estimator, a robust regression technique, is utilized in order to consider the existence of outliers. First results show a sectoral NUE around 60%, with significant differences among and within farm types. The mean NUE increases from dairy, over pig and poultry, towards arable farms. Also, all farm types with animal husbandry miss the goal of a 60% farm-NUE, a level required for meeting the national Sustainable Development Goal by 2030. The explanatory models show significant results for various independent variables, such as farm size, soil fertility, or education level. However, limitations regarding organic fertilizer imports need to be considered. In order to achieve the ambitious (inter-)national sustainability goals, further efforts are needed, and efficiency reserves of all farm types must be identified and mobilized henceforward. For designing agri-environmental policies to improve N management, the NUE can serve as a robust and informative performance indicator whose relevance will further enhance due to the addressing and focusing on resource efficiency in current political and societal visions.

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Measures to reduce nitrogen losses in Spanish livestock. Implementation of an electronic tool to estimate, monitoring and reporting N emissions (ECOGAN).

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The Spanish authorities are strongly committed to promoting a rational use of nitrogen in agriculture in general and livestock farming in particular. Important changes in legislation have been introduced to reduce nitrogen losses in the main animal species. The package of legislative proposals includes specific measures to reduce nitrogen excreta and reduce ammonia emissions through the application of Best Available Techniques (BAT).

In addition, farm operators are responsible for carrying out a complete nitrogen balance, estimating their emissions in their various forms, and BATs to avoid or, where this is not possible, reduce emissions and the impact on the environment as a whole. They are also responsible for notifying the implementation of these techniques to the competent authorities.

In order to provide the livestock sector and the competent authorities with an electronic support at national level to facilitate the calculation, monitoring and notification of the emissions of each farm, as well as the notification to the General BAT Register, the Ministry of Agriculture, Fisheries and Food has developed the ECOGAN computerized system. It is currently available for the swine species; the rest of the livestock species will be incorporated as the corresponding management regulations are implemented.

The estimates of these emissions are made in accordance with updated guidelines established by the Intergovernmental Panel on Climate Change (IPCC) and the European Monitoring and Evaluation Program (EMEP/EEA) and other institutions with competence in the matter (including TFRN), allowing the estimation of ammonia, methane and nitrogen oxide emissions with an advanced level of complexity, in such a way that they are compatible with the Spanish Inventory and Projections System (Sistema Español de Inventario y Proyecciones).

Maize diversification and N fertilization rate impact on crop productivity and N use efficiency in flooded irrigated systems under semiarid Mediterranean conditions

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Maize monoculture is a common system in irrigated areas of the Ebro River Basin (ERB, NE of Spain). It is characterized by an intensive management that implies high N inputs, leading to a high crop productivity, but with high environmental impacts. Double-annual cropping systems are an interesting alternative to increase crop diversity in these regions. On the one hand, they can increase the profitability per land unit, and on other hand, they provide several environmental benefits, including the improvement of the N use efficiency (Maresma et al. 2019). However, most of the studies were conducted in systems using sprinkler irrigation; and more information is needed in traditional flooding systems, as it is still a widespread irrigation method at the Central ERB.

The main objective of this work was to study the impact of cropping diversification and different N rates on the crop performance and on the N use efficiency, in a flooded irrigated maize under Mediterranean conditions. Three cropping systems (maize monoculture; and pea-maize and barley-maize double cropping systems) and three N rates (unfertilized, medium, and high rate) were evaluated in a field experiment located in Zaragoza (Spain) during two years. Before termination of each crop, the aboveground biomass was determined and different crop components were measured. Grain yield was measured at harvest. Nitrogen concentration in the grain and stover were determined. Each year before sowing and after harvest, soil samples (0-90cm) were collected from each plot to measure soil inorganic N content. Different N use related indicators were calculated.

The results indicated that crop diversification may provide different environmental advantages compared to maize monoculture (i.e. higher soil coverage, greater N supply in the systems including legumes and lower residual N). However, it was clearly observed that the management of double-cropping systems with flood irrigation is challenging, and this entailed crop yield penalties, that led as well to lower N use efficiencies. Therefore, double-cropping systems under flooded irrigated conditions are interesting to increase sustainability, but further research is needed to identify proper management practices to maximize its potential and be a profitable alternative for farmers.

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BIOLOGICAL NITRIFICATION INHIBITOR-TRAIT REDUCES SOIL NITRIFICATION AND IMPROVES NITROGEN UPTAKE IN WHEAT UNDER AMMONIUM OR NITRATE FERTILIZATION

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Synthetic nitrification inhibitors (SNI) and biological nitrification inhibitors (BNI) are promising tools to limit nitrogen (N) pollution derived from agriculture. However, SNIs performance varies substantially depending on soil conditions, and modern wheat cultivars lack the ability to exude BNIs. Fortunately, the chromosome region (Lr#n-SA) controlling BNI production in *Leymus racemosus*, a wild relative of wheat, was introduced into two elite wheat cultivars, ROELFS and MUNAL. These two high BNI isogenic lines can inhibit nitrification in acidic soils under ammonium nutrition. We evaluated the BNI trait expression of ROELFS-BNI and MUNAL-BNI in the field, and under ammonium and nitrate fertilization in microcosms. Using BNI isogenic lines could be an efficient technology with potential use worldwide, in support of more sustainable agricultural and environmentally friendly agronomic practices. The introduction of the BNI-trait had no negative impact since Control and BNI-isogenic lines from ROELFS and MUNAL presented similar agronomic performance and plant development. In the soil, ROELFS-BNI and MUNAL-BNI plants decreased ammonia-oxidizing bacteria (AOB) abundance by 60% and 45% respectively, delaying ammonium oxidation without reducing the total abundance of bacteria or archaea. Moreover, under nitrate fertilization, BNI-isogenic lines reduced soil nitrate content. ROELFS-BNI and MUNAL-BNI plants showed a reduced leaf nitrate reductase (NR) activity and a higher amino acid content compared to BNI-trait lacking lines, indicating that plants preferred ammonium as N source. In addition, the benefits from introduction of BNI-trait into ROELFS and MUNAL wheat cultivars were also noticeable for nitrate fertilization with improved N absorption.

Precision agriculture at farm level: innovative soil technologies and fertilization efficiency to reduce the N footprint of Portuguese wine

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Nitrogen (N) is a key nutrient in crop production and crucial in vineyard management. Agriculture is one of the more important activities where action can and must be take n to promote N losses mitigation and create awareness about the impact of excessive N inputs. The efficient use of N as fertilizer was tested in several field experiments to produce wine of low N footprint.

Conventional fertilization practices in each farm served as control (treatment A – higher N dose) and three other rates of N inputs (treatments B, C and D, being D the lowest N dose) were applied to vineyards located in two different regions in Portugal, from the variety *Alicant Bouschet.* Innovative soil probes were set up in the field, at two different depths, to monitor nitrate leaching potential risks in real time. Several samples of soil, plants and fruits were collected for chemical analysis along the growing cycle. At the harvest time, grapes of each treatment were collected, weighted, and vinified to produce a type of wine per treatment.

Different N fertilizer management practices applied in the field of each farmer found no significant differences in fresh grapes production yield and quality. Treatments B and C (medium N doses applied) resulted in the higher grape production (t/ha). The reduction of N fertilization did not negatively affect production yield neither the potential alcohol content of wine. The conventional farmer practice of higher N inputs in vineyards production did not result in the best yield. The innovative soil probes tested in the vineyard fields were an added value to farmers allowing the control of N inputs and soil pollution and improving N use efficiency through better agricultural practices. Wines of low N footprint were produced with a very good quality and taste.

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Right place, right time: connecting soil N and plant uptake for greener agriculture

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Nitrogen (N) is a primary nutrient that is essential to the survival of all living organisms. Crops are inefficient in their N use, losing 50-70% of applied N, which transforms to reactive nitrogen Nr, to the environment. This results in increased Nr species, such as NH3 and nitrous oxide (N2O) in the atmosphere and nitrate (NO3−) in terrestrial and aquatic ecosystems, which has significant consequences for climate change and environmental toxicity. In Australia, agriculture is responsible for ~80% of N2O emissions. One of the approaches to tackle the problem of unwanted N losses from the plant/soil system is through the use of novel inhibitors delaying degradation with fertiliser formulation. My current ARC funded project aims to test the effects of N movement from controlled growth solutions to plant on root growth and morphology without/with novel inhibitors compared to the commercial inhibitors in using root growth microcosms, called 'ROOT-TRAPR'.

This proposed project aims to transition into real world scenarios using pots and a range of soil types to achieve three main objectives:
1)To identify beneficial microbes interacting with plant roots and contributing to improved N uptake and how these interactions are impacted by new fertilizer formulations
2)To characterize in detail the rhizosphere biochemistry underlaying beneficial microbe interaction under different N supply conditions (ie with/without novel inhibitors)
3)To test the efficacy of candidate high-performing novel inhibitors on plant growth performance and ultimately yield

Results obtained from this project will provide important knowledge to identify the mechanisms underpinning plant root-soil-microbiome interactions in response to new fertilisers and eventually plant growth and N use efficiency of target crops along with the knowledge on N release of new fertilisers in response to plant signalling molecules for N acquisition.

Android Based Fertilizer Management Tools for Increasing Nitrogen Use Efficiency in the South Asian Countries: A Review

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Nitrogen (N) is a blessing for the human beings, and at the same time it is the godfather of environmental pollution. The global challenge is to achieve a synergy between these two opposite scenarios. The N reserve in soil decreasing continuously, while application of inorganic N fertilizer increasing dramatically to produce food, feed and fiber. At present, the global requirement of N fertilizer in agriculture is 110 million tons (Mt), while in the South Asia is 24.25 Mt. Average N use efficiency (NUE) in agriculture rarely exceed 30-40% which depicts that a large amount remains unutilized as reactive N (Nr). The South Asia region is a global hotspot of Nr which catastrophically damaging the environment and collapsing the ecosystem functions. Scientists across the world are belligerent to find a better option to increase NUE. Different soil and crop management practices have already been identified and found effective to increase NUE but not efficient to halve N waste by 2030 as emphasized in the 'Colombo Declaration' by UNEP. The unprecedented progress in the android based mobile technology and high speed internet connectivity across the South Asia region might open a new avenue for optimization of N fertilizer in crop production. Many free N/fertilizer management Apps are available across the South Asian region and the world as well. Information on such fifty fertilizer management Apps were collected and characterized considering some common criteria *viz*. target users, target crops, data requirements, user friendliness, accessibility, cost-effectiveness, adoption rates, barriers to adoption, *etc*. Some Apps are found user friendly and provide quantitative N guidance, but most of them are generalized and do not use farmers' field data like soil nutrients, yield goal, *etc*. while calculating N requirement. The study revealed that mobile based suitable, efficient, and solely N guidance tools are still demanding.

Acknowledgements
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Apparent nitrogen balance under different cover crops managements

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The use of cover crops (CCs) is becoming of utmost importance to increase the environmental sustainability of agricultural production systems. It has been demonstrated that CCs significantly affect the dynamic of soil fertility and especially the nitrogen (N) cycle. Different CCs managements, including the use of diverse species, termination dates, and residues managements, can differently affect the CCs' role in the N mineral-immobilization turnover, and the N availability for the subsequent cash crop. The analysis of the N release from the CCs residues is thus essential to optimize the management of this agronomic practice. In this context, the present study aimed to compare two winter CCs management systems in the first two out of three years succession, with waxy maize as a summer cash crop. The 2 years research study (2019-2021) was conducted on a 6.5-ha field in North-east Italy (45°20′53″ N, 11°57′11″ E). The CCs systems included a fixed treatment with a gramineous species (triticale), a 2-year gramineous-leguminous succession (rye, clover), and control with No CCs (weeds). Simulated values of N release were investigated using the CC- NCALC Model and considering residue incorporation on three termination dates (end of January, February, and March). An apparent N balance was performed analyzing the residues' N content and the soil NO_3-N content in the first 0-40 cm layer. Finally, the maize biomass yield at waxy maturity was analyzed in each treatment. The results of the N balance showed significant differences among treatments. In the two years, the soil NO_3-N content at CCs termination decreased on average by 51.7 (No CCs), 29.9 (fixed), and 35.9 kg ha^{-1} (succession) compared to the NO_3-N content measured at CCs sowing time. In the No CCs and fixed treatments, the residues' N content was equivalent to the 62.6% and 95.7% of NO_3-N content lost from the 0-40 cm soil layer (above reported), respectively; in contrast, in the succession treatment, the N balance showed residues' N content equal to +16.4% of the NO_3-N content lost. The CC-NCALC Model estimated that the N released by the residues (terminated in March) during the following maize season was equal to 36.4%, 21.5%, and 30.8% of the total N content in the residues of No CCs, fixed and succession treatments, respectively. Comparing different termination dates, the results showed that rye, clover, and weeds accumulated N in their biomass with a constant linear increase, while triticale showed a significant increase in biomass and N uptake early in the winter (end of January) and then remained stable. This might have affected the triticale biomass quality, determining the N mineralization-immobilization turnover after termination. The maize biomass yield was indeed lower after triticale (16.2 Mg ha^{-1}) than after the No CCs and succession treatments (+7.1% on average).

Biochar and compost impact on soil N processes: results from a long-term field study in an organic olive tree crop

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Soils from Mediterranean areas, usually characterized by a low organic matter content, require high N inputs to maintain and further increase their productivity. This increases the risk of reactive N losses to the environment, which further promote global warming and eutrophication processes. Compost and biochar amendments have been postulated as advantageous strategies to increase soil C build up and sustain soil fertility. Additionally, the interaction between these two amendments have been previously reported with promising synergistic effects (Harindintwali et al., 2021).

Compost, biochar and their mixture (90:10) were applied to an organic olive tree crop every two years at a field rate of 6 t ha^{-1}. Control plots did not receive N nor C inputs, whereas compost, mixture and biochar treated plots received, in each application, 141, 132 and 50 kg N ha^{-1} and 2.15, 2.34 and 4.04 t C ha^{-1}, respectively. The effect of these organic amendments on soil N availability and the N related microbial community was assessed 8 years after the experiment started.

Mineral N was similar in all treatments and the differences in N availability between treatments was a consequence of the organic soluble N fraction. Although the highest nutrient input corresponded to the compost amendment, the highest rate of N availability was reached in the mixture amended plots. Water soluble N in the soil was positively correlated with the dissolved organic C (DOC), the denitrifying enzyme activity (DEA) and the relative abundance of *nosZ* genes, which encode the enzyme system catalyzing the last step of the denitrification process. Microbial communities related to the soil N cycle had contrasting responses to different organic amendments, i.e. archaeal community was enhanced by compost amendment while bacterial community showed the opposed trend, and the mixture treatment favored the development of the fungal community. This affects the mechanisms transforming N in the soil and the N lost in the form of N_2O, a potent GHG which usually correlates with N availability.

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Effect of different types of fertilizers on nitrogen use efficiency of rice and emission of greenhouse gasses

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Rice cultivation is considered as one of the important anthropogenic sources of greenhouse gas (GHG) emissions such as nitrous oxide (N_2O) and methane (CH_4) as a result of inefficient input management. Soil type, climate, soil redox potential, water management and method of application and type of fertilizers are some of the important factors that control agricultural GHG emission. Therefore, this study was conducted to assess the nutrient use efficiency and GHG emission from three fertilizer types namely; Department of Agriculture (DOA) recommended mixture (T1), Nano fertilizer (T2), slow release fertilizer (T3) and compared with no fertilizer application. The experiment was conducted under open field conditions at the experimental field of Mahailuppallama Sub campus, University of Peradeniya. Plant height was significantly different in 6 and 9 WAP and tiller number showed a significance difference 4, 6 and 8 weeks after planting. Significantly highest ($p=0.0024$) flag leaf chlorophyll content was obtained from the DOA recommended treatment. The highest grain yield of 3938 kg ha^{-1} was reported from Nano fertilizer while the lowest yield (2,738 kg ha^{-1}) was from the no fertilizer treatment. A slight N_2O emission was recorded without a clear pattern while CH_4 emission was not detectable during the growing season. Overall results showed that the Nano fertilizer treatment exhibit higher nutrient use efficiency while reducing N_2O emission compared to other treatments suggesting the potential of use of Nano fertilizer for mitigating climate change while increase the rice yield.

Assessing nutrient use efficiency of different fertilizer types and weed control systems of tea fields in Hapugastenne estate in Maskeliya plantations plc

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Ways to improve Nutrient Use Efficiency (NUE) and control weeds by reducing the complete dependency on chemical control is essential to enhance sustainability in the tea sector. This study was initiated to investigate the impact of different weed and fertilizer management measures on soil nutrient status, NUE and green leaf production of tea. A Field experiment was conducted in VP tea fields of TRI 2025 (*Camellia sinenses* L.) to assess the NUE of Slow Releasing Fertilizers (SRF) in already established Herbicide Free Integrated Weed Management (HFIWM) and chemically weed controlled mature tea fields in Hapugastenne Estate in Maskeliya. The experiment was a Split-Plot Design with weed control as the main plot factor with two levels (HFIWM and chemically weeding). Sub plot factor was fertilizer with six treatment combinations of TRI recommended 100% U709 (200 kg/ha/3months), 75%U709+25%SLF, 50% of U709 and SLF, 25%U709+75%SLF, 100%SLF (100 kg/ha/3months) and no fertilizer treatment. Green leaf yield and SPAD meter readings were taken at 12 day intervals and soil measurements were taken from 0-15 cm depth initially and three months after treatment application. Results showed a significant yield increment ($P < 0.05$) in HFIWM compared to chemical weeding fields. Among six treatments 100%SLF and 25%U709+75%SLF showed higher yields in both HFIWM and chemical weeding fields. Overall, the SPAD meter readings were greater in HFIWM compared to chemical weeding fields. In both fields, application of 100% SLF resulted a greater AE_N 30%) compared to 100%U709. There was no significant difference ($P>0.05$) in soil properties of CEC, total N, exchangeable K, available P and organic matter content of initial and 3 months after treatment application. Addition of organic matter content in HFIWM fields was 1212 kg/ha/3months as dry weight. HFIWM improved NUE, soil properties and biodiversity in tea plantations exhibiting significant improvement in many parameters over chemical weeding.

Introduction of legumes in maize double cropping systems: Effects on soil and plant N dynamics

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Maize is one of the main irrigated crops in northern Spain. The traditional cropping system used has been intensive monoculture, which requires a large amount of inputs for its cultivation, and being often affected by weeds, pest and diseased. One practice that allows for the maintenance of the sustainability of farms is the switch from maize monocultures to multiple cropping systems with the use of legumes. The aim of this work was to evaluate the impact of double cropping systems, through the introduction of different legumes prior to maize, on soil and plant N dynamics. The study was carried out in Agramunt (NE Spain). A long-term tillage and N rate fertilization field experiment established in 1996 under rainfed conditions was transformed into irrigation with maize (*Zea mays* L.) monocrop as cropping system in 2015, and into a diversification experiment in 2018. Maize monocrop (MC) against a legume-maize double cropping (DC) were compared. Pea for grain (2019), vetch for green manure (2020), and vetch for forage (2021) were the legumes employed. The soil management used was no-tillage and the N fertilization rate was 200 kg ha^{-1} in MC and 150 kg ha^{-1} in DC respectively. Although DC received less N fertilization than MC, soil mineral N levels were similar for both treatments. This indicates that the legumes used were sufficient to replace the lower fertiliser application in the DC. A biological fixation of 57, 84 and 39 kg N ha^{-1} was found for the legumes used in 2019, 2020 and 2021 respectively under DC. In addition, the use of legumes resulted in 18 and 30% increase in the b-glucosidase and dehydrogenase soil enzyme activities respectively, which implies a higher mineralisation of organic matter in DC system. Maize grain yields were 23, 20 and 28% higher in DC than in MC in 2019, 2020 and 2021. This would be related to a better use of N by the DC system, as N is supplied more gradually. The higher mineral N fertilization in the MC also led to rapid increases in soil N concentration which resulted in maize leaf NO_3 levels 46% higher in MC than in DC. These differences in N dynamics originated that the NUE was on average 54% higher in DC than in MC during the years studied.

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EFFECT OF NITROGEN MANAGEMENT SYSTEM ON GROWTH AND YIELD OF RICE AND MAIZE IN CENTRAL TARAI, NEPAL

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Rice–maize systems are rapidly expanding in South Asian countries due to higher yield and profit potential from winter maize, and its increasing demand from poultry and fish feed industries. An on-station trial was conducted at research farm of National Rice Research Program, Nepal in 2021/22 under the aegis of South Asia Nitrogen Hub (SANH) Project to access the effect of different nitrogen sources and amounts on productivity of rice and maize crops. The experiment was conducted in randomized complete block design with eight treatments (N omission; recommended dose of Nitrogen (RDN); RDN+25%; RDN-25%; cattle manure; poultry manure and industrial manure adjusted as per RDN each; and briquette urea adjusted as per RDN – 35%), and was replicated four times. The recommended dose of nutrient for rice and maize crops in Nepal are 120:40:40 and 120:60:40 kg NPK per hectare, respectively. Green gram was cultivated during spring as baseline crop and incorporated in soil before the rice crop which was followed by maize. Growth, yield and yield attributing parameters of rice and maize crop were recorded and analysed by R-stat software. There was no significant effect of N management on growth, yield and yield attributes of rice crop. However, the highest panicle length (26.1 cm) was recorded in briquette urea plot; highest biomass yield (6.5 t/ha) in RDN + 25% plot; and highest grain yield (2.9 t/ha) in industrial manure plot. Maize was planted after rice using the same treatments. Plant height of maize was recorded highest in industrial manure plot at 30, 60 and 90 days after sowing (DAS), however it was highest in briquette urea plot at 120 DAS and at harvest. Number of grains per cob (243.8) was significantly higher in RDN + 25% plot, however thousand grain weight wasn't significantly different among the treatments. Grain yield (7.2 t/ha) and stover yield (15.4 t/ha) was significantly higher in RDN + 25% plot, however the harvest index wasn't significantly influenced by N management. Based on the date form one season experiment on rice and maize each it can be concluded that 25% addition to recommended N fertilizer increased the yield of maize significantly but no significant difference was found among the treatments in case of rice.

Key words: rice, maize, manure, fertilizer, Nitrogen, yield

Improving nitrogen fertilisation efficiency by connecting soil nitrogen availability and crop yield through the design of novel urease inhibitors

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By the year 2050, the world population is predicted to approach 10 billion people, with the question of how to feed the increasing population of utmost importance. The known correlation between plant growth and nitrogen (N) uptake allows for maximised crop yield, and through manually applying nitrogen fertilisers such as urea and ammonium salts, N content in soil can be increased and plant growth maximised. However, excessive use of nitrogen fertilisers can result in significant nitrogen losses to the environment of up to 50%, leaving less available for plant uptake. Mitigating N-loss can be achieved by improving nitrogen use efficiency using synthetic urease inhibitors (UIs) to slow the enzymatic conversion of urea fertiliser to plant-available nitrogen, reducing accumulation and loss to environment. Current commercially used UIs whilst effective at slowing down this process, are both short-acting and significantly less effective in soils with a naturally low pH (<5.5), as commonly found all over Australia. This project aims to develop new generation UIs that are more effective and applicable in diverse soils compared to commercial inhibitors to improve N efficiency. These compounds will be designed and screened for inhibitory potential through a combination of *in vitro* and *in silico* experiments before promising candidates being tested on Australian soils and plant model systems.

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Urease inhibitors effects on the nitrogen use efficiency in a maize-wheat rotation with or without water deficit

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The use of urease inhibitors in irrigated systems decreases both soil ammonium (NH_4^+) and nitrate (NO_3^-) availability, and thus, could be an easy tool to reduce N loss by ammonia volatilization and NO_3^- leaching. The main goal of this experiment was to assess the effect of urease inhibitors in the N use efficiency, N losses and economic impact in a maize-wheat field experiment. In this study, 10 treatments were compared, combining the urea fertilizer with or without urease inhibitor, applied in one or two dressings and under optimal or suboptimal irrigation (Allende et al., 2021). A single application of urease inhibitor (IN_{1d}) coupled with the conventional urea can help to reduce the nitrate leaching risk both during the maize period (even when compared to the two dressing) and after harvest. In addition, this improvement was achieved together with an increase on the economic benefit, even when compared with the application of the same amount of regular urea split into two dressings. Under low water availability systems, the benefits of applying urease inhibitors increased respect to the application of regular urea, making this technique a very promising strategy for adaptation to the climate change under arid and semiarid regions.

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Nitrogen, potassium and sulphur availability from residue-based fertilisers applied singly or combined

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In organic farming systems, nutrients taken up by crops should be replenished by the recycling of agricultural and urban organic waste to close nutrient cycles. However, the availability of organic wastes permitted for application in organic farming is limited, and organic farmers usually have to apply manure from conventional farms, which are considered to be contentious. Alternative nutrient sources acceptable for application in organic farming are therefore needed to supply available nutrients to maintain or increase organic food production. In this study, we investigated the ability of manure, digested manure, manure co-digested with the organic fraction of municipal solid waste, Fertigro®, and ash from straw to supply N, K and S to ryegrass grown in pots, and establish whether the use of complex mixtures to obtain more suitable nutrient ratios which may benefit plant growth. Digested manure and manure co-digested with the organic fraction of municipal solid waste produced greater plant growth and N recovery than manure, while no significant differences were observed in terms of K recovery. Fertigro® showed similar plant growth and nutrient uptake to the mineral S and N positive controls, while the addition of straw ash demonstrated even greater K recovery than that observed for the mineral K positive control. The mixture of Fertigro® with manure co-digested with the organic fraction of municipal solid waste and ash was outstanding among the waste-based fertilisers in terms of amounts of N, K and S available nutrient are supplied for plant uptake. However, field trials are required to confirm these benefits under field conditions.

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Impact of Different Fertilizers of Nitrate and Ammonium Forms and Slow Releasing, on Growth, Yield and Nutrient Use Efficiency of Rice (*Oryza sativa*)

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The rice sector in Sri Lanka has a nitrogen use efficiency of about 25-30%. At the University Experimental Station in Dodangolla, Sri Lanka, field and pot experiments were conducted to compare the growth, yield, and agronomic nitrogen use efficiency (AE_N) of irrigated rice with various nitrogen fertilizers and rates to the Department of Agriculture's (DOA) Urea recommendation. Both experiments consisted of 8 treatments. They were; no N applied, 100% DOAN provided as Urea (Control), 75% AN, 75% U+UI, 75% Osmocote, 50% AN, 50% U+UI, 50% Osmocote. The Field experiment revealed, there was no significant ($p<0.05$) yield difference between the 75 % U+UI treatment and the control. The 50 % U+UI and 75 % U+UI treatments have the highest AE_N, showing 34.0 % and 26.8 % increases respectively over control. From the pot experiment, there was no significant difference ($p<0.05$) between the 75 % U+UI and the control. The 75 % U+UI, which has a 26.3 % increase over control, has the highest AE_N. Results showed, there could be a significant yield loss due to ammonia volatilization from urea in field conditions, which can be significantly reduced by Urease inhibitors. In the pot experiment, urea performed better than AN when flooded.

Effect of stabilized fertilizers of urea with Dicyandiamide, N-butyl thiophosphoric-tramide, Coated urea, and Biochar on Nitrogen Use Efficiency in Rice

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Nitrogen use efficiency (NUE) in paddy cultivation in Sri Lanka ranges from 15-30 %. A field and a pot experiment were conducted at the University of Peradeniya Experimental Station at Dodangolla, with the objectives of assessing yield and Agronomic NUE (AE_N) of irrigated paddy cultivation with the application of stabilized fertilizer of urea (with Dicyandiamide [DCD]) and N-(n-butyl) thiophosphoric-tramide (NBPT), coated-urea, and biochar compared to the Department of Agriculture Nitrogen recommended rates (DOAN). Both experiments consisted of 8 common treatments, namely, no N (T1), 100% DOAN provided as urea (control:T2), 50% of DOAN+M1(30% NBPT+15% DCD:T3), 50% of DOAN+M2 (20% NBPT:T4), no N+biochar (T5), 100% DOAN+biochar (T6), 50% of DOAN+M1+biochar (T7), 50% of DOAN+M2+biochar (T8). Pot experiment consisted of 2 additional treatments of 50% of DOAN+50% of DOAN provided as coated-urea (CU:T9) and 50% of DOAN+(M1+M2)+50% of DOAN provided as CU+(M1+M2:T10). The M1 and M2 rates were 10% of the amount of urea used. Results of the field experiment showed a significant ($p<0.05$) yield difference among treatments, and T3 and T7 recorded 22.2% and 8.3% greater yield than the control (7.08 t/ha). The highest AE_N was reported in T3, which was a 28.34 kg yield increase kg^{-1} N applied compared to the control. Results of the pot experiment showed significant ($p<0.05$) yield differences among treatments, recording 61% and 29.5% greater yield in T7 and T8, respectively, compared to the control (5.06 t/ha). The highest agronomic efficiency of applied N (AE_N) was reported in T7, which was 30.9 kg yield increase kg^{-1} N applied compared to the control. Results showed that usage of N fertilizer could be reduced by 50% with the application of stabilizers of M1 and M2, while increasing yield potentials and subsequently providing significant economic and environmental benefits.

Impact of control release and bio fertilizers on nutrient use efficiency and productivity in Tea

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Field experiment was conducted in Newburge tea estate, located in Uva province (IU3agro-ecological region) with the objective of assessing the impact of control release fertilizer (CRF) and bio-fertilizer application to tea fields in the upcountry intermediate zone of Sri Lanka on tea productivity and nutrient use efficiency. Two separate experiments were conducted in a conventional tea field and non-conventional tea field. Seven treatments were applied to conventional field and six treatments were applied to the non-conventional field. Treatments of both experiments were arranged in Randomized Complete Block Design with three replicates. Fresh leaf weight, inter-nodal length and dormant bud percentage were measured with seven days plucking intervals during experimental period. Agronomic Efficiency (AE) and Value Cost Ratio (VCR) were calculated to determine the efficiency of different fertilizer treatments. Fresh leaf yield was significantly different ($p<0.05$) among treatments in both experiments. Combination of bio-fertilizer and inorganic fertilizer applied treatments showed higher yields ($p<0.05$) than other treatments which were treated with only inorganic fertilizer. Inter-nodal lengths between first and second leaves, and second and third leaves were different ($p<0.05$) among treatments. Highest AE was recorded in T7 (CRF + bio-fertilizer). The highest VCR was recorded in 100% U709 (T2) whilst the lowest was in CRF + bio-fertilizer (T7). Yield ranged from 1691.76kg/ha to 1997.31kg/ha in non-conventional field. The highest yield was recorded in 50% inorganic fertilizer + bio-fertilizer (T5) followed by CRF (T6). Intermodal lengths between first and second leaves, and second and third leaves were different ($p<0.05$) among treatments. Combination of bio-fertilizer and organic matter application showed higher fresh leaf yield and intermodal lengths than other treatments, which were treated with only organic matter.

First experiences in chickpea inoculation with indigenous rhizobia in Croatia

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The application of beneficial microorganisms can significantly enhance agricultural sustainability and environment protection. Plant growth-promoting rhizobacteria (PGPR) are among the most useful and promising microbial groups because of their beneficial effect on the overall well-being of the plants. PGPR represent a very diverse group of soil bacteria that also includes various nitrogen-fixing and phosphate solubilizing bacteria as well. Nitrogen fixation is a microbiological process in which molecular nitrogen is converted into available form for plants. Symbiotic associations between special group of nitrogen-fixing bacteria (rhizobia) and legumes have a unique role in agriculture because the utilization of this natural process enables significant reduction of mineral nitrogen fertilization. Like most other grain legumes, chickpeas (*Cicer arietinum* L.) are a valuable source of proteins in a healthy diet and it is an important crop especially in the Mediterranean basin. The objective of the present study was to evaluate the beneficial effects of chickpea inoculation with indigenous strains of rhizobia and phosphate solubilizing bacteria under different environmental conditions. Field trials were set up at following locations in Croatia: i. continental part (Zagreb) and ii. Mediterranean part (Zadar-Petrčani). At location Zagreb, the inoculation with both rhizobial strains caused significant increase in nodule number and nodule dry weight in comparison with uninoculated plants. The inoculation with indigenous rhizobial isolate resulted in better nodulation and higher N content in plants in comparison with inoculation with reference strain. The effect of rhizobial inoculation on fresh plant biomass and total nitrogen content in plants was determined as well. These results strongly confirm the importance of strain selection in the use of inoculation. At location Zadar - Petrčani the effect of inoculation was not so expressed and the differences in nodulation, plant biomass and N content in plants were not significant. The reason for such results is in chickpea growing areas in Croatia since the chickpea is mostly grown in Mediterranean region while in other parts is only sporadically grown. The obtained results showed that the existence of natural populations of rhizobia in the soil can limit the success of inoculation. Different values for seed yield were determined depending on location and application of particular strain for inoculation. Further investigation is needed in order to select rhizobial strains with enhanced symbiotic performance which will enable reduction of mineral fertilizers and impact of unfavorable environmental conditions.

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Ammonia Energy: The future for Power Generation and Storage

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Ammonia is the second most produced chemical worldwide after sulphuric acid, mainly recognized due to its uses as a fertiliser. Around four-fifths of all ammonia is used to produce nitrogen fertilisers, such as urea and ammonium nitrate, responsible for half of the world's food production.

Currently, the increasing interest to replace carbon intensive energy systems is creating an opportunity for molecules such as hydrogen and ammonia to provide a zero-carbon energy alternative. As an energy vector and storage medium, ammonia presents significant advantages over hydrogen. It holds all the benefits of $H2$ while also having better physical characteristics, lower cost per unit of stored energy, higher volumetric energy density, easier production, handling, and distribution.

With the current applications of ammonia as a fertiliser and chemical compound, existing knowledge, and infrastructure, along with the attractive characteristics as a zero-carbon fuel, recognition for the use of $NH3$ energy is increasing. Industries are investing in this chemical as an energy carrier and for power generation all around the world.

Nitrogen Use Efficiency in radish fertilized with N-doped biochar-based fertilizers compared to synthetic fertilizer

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Current environmental and economical boundaries entail the need to improve the efficiency of the fertilizers by reducing N losses to the environment and increasing N use efficiency (NUE) of the crops. Researchers are increasing their attention to biochar-based fertilizers because they could further promote the reported benefits associated to the co-application of stable forms of organic C and nutrients in cropping systems, enhancing the NUE by reducing both gaseous losses and NO_3^- leaching (Rasse et al. 2022).

In this work, we compared three types of fertilization: urea, a mix of urea and biochar and two biochar-based fertilizers. The objective was to evaluate the NUE and their impact in other agronomical parameters of a radish crop. We measured N_2O emissions, radish yield, N uptake by plants and N remaining in the soil at the end of the experiment. In addition, we calculated N_2O yield-scaled emissions, which links N_2O emissions and plants N uptake. Biochar-based fertilizers were produced from olive tree-pruning biochar pyrolyzed at 400 and 800 °C as described in Castejón-del Pino et al. (2021). Radish plants were cultivated in soil pots into a greenhouse under climatic controlled conditions. Biochar-based fertilizers showed promising effects with a significant reduction of 47% of the N_2O emissions compared to the plants fertilized with urea and the mix of urea and biochar, being the biochar-based fertilizer made with biochar produced at 800 °C the fertilizer treatment with the lowest N_2O emissions. There were no significant differences in radish yield and plant N uptake between biochar-based fertilizers and all the treatments fertilized with urea.

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Sorghum bicolor as producer of biological nitrification inhibitors for reduced N loses in wheat crop rotation systems

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The low nitrogen use efficiency (NUE) of crops in highly fertilized agricultural productions entails major losses of N from the plant-soil system via nitrate (NO_3^-) leaching and N_2O gas emissions produced by soil microbial processes. During soil nitrification the rapid conversion of ammonium (NH_4^+) into NO_3^-results in inefficient use of both soil N and applied fertilizer-N by the target crop. Biological nitrification inhibition (BNI) is a plant-mediated process in which organic compounds are exuded in the rhizosphere to suppress the activity of ammonia-oxidizing bacteria and archaea. Thus, the release of BNI to the soil limits the amount of N cycled via the nitrification pathway, reducing N losses and representing an environment friendly and low-cost alternative to the application of chemical inhibitors. BNI exudation capacity has been identified for several species, including *Sorghum bicolor* or Brassicaceae species, that are commonly cultivated as catch-crops or included in crop rotation systems. Thereby, the incorporation of new crop varieties with BNI potential into crop rotations is proposed as mitigation strategy to further retain NH_4^+ in soils and increase soil N pools, reducing the requirement of N fertilizers for the subsequent target crop. Such integrated approach represents a sustainable tool to develop low-nitrifying agronomic environments, minimizing N leakage and improve NUE in agricultural systems. With this aim, a 2-year field trial (Fustiñana, Navarra) was stablished in 2021 in which four *Sorghum bicolor* varieties (two silage types and two mixed types) are characterized for their BNI-producing capacity, testing their inhibitory effect over soil ammonia-oxidizing bacteria (AOB), in rotation with a winter wheat culture. The efficiency of Sorghum plant to affect soil N cycle and promote N availability for the subsequent wheat crop is investigated regarding soil mineral N contents, as well as yield and NUE parameters of both Sorghum and wheat target culture. This study was performed under various NH_4^+-based fertilization regimens, with the supply of urea with or without urease inhibitor N-(n-butyl)thiophosphoric triamide (NBPT), that will increase the presence of NH_4^+ in the soil, potentially enhancing the BNI capacity of the *Sorghum* plants.

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Increased nutrient efficiency of new upgraded mineral fertilizers with Rhizobium strain

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New Rhizobium strain enhanced mineral fertilizers from Fertiberia perform higher fertilizer N efficiency in microcosm with cereal crops. This Rhizobium strain-mineral fertilizers are registered under the current Spanish fertilizer regulation. Rhizobium are widely known for their PGPR characteristics. In these new fertilizers they are used as microbial plant biostimulants that improve the nutrient use efficiency of crops as free living bacteria. Rhizobium strains are among the microorganisms included in the current Regulation (EU) 2019/1009. After Dobermann (2007) a number of Agronomic indices have been proposed for the short-term assessment of Nitrogen Use Efficiency and its components. These indexes have been cited by the newly released standard CEN/TS 17700-2:2022 to validate the claim for enhanced nutrient use efficiency from the use of a plant biostimulant.

The results show that the addition of mineral fertilizer with PGPR produced increases in nitrogen efficiency indices, such as the physiological efficiency of acquired nutrient (PE 7-15% increase), the internal utilization efficiency (IE 4 – 11% increase) or the agronomic efficiency (up to 75% increase).

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The optimization of nitrogen application on yield of potato crop by Finder® a biofertilizer produced with MAMPs Enhancer Technology.

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Finder® is a biofertilizer consortium based on *Azospirillum* and *Sinorhizobium* PGPRs microorganisms, resulting from innovative fermentation technology: MAMPS Enhancer®. It is an efficient biological nitrogen fixer that provides a large amount of molecular elicitores that improve microbial biofilm root colonización and promote plant growth. Applying the minimum range of nitrogen fertilization to achieve optimal production, FINDER® increases its nutritional efficiency, significantly enhancing productivity by 9% compared to control. FINDER® is a suitable complement for conventional nitrogen fertilization.

TRICHODEX, Biobased company, focuses on development of biotech solutions based on plant-microbiome-soil interactions to improve agriculture productivity and to guarantee food security and sustainable use of natural resources.

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Comparative effect of Zn coated urea and conventional urea on N_2O emissions in different soils under crop plantation and bare soil conditions

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About 50% of the world's food production relies on synthetic N fertilizer application, hence, to meet food production, its use has increased tremendously during the last 4 to 5 decades. The use efficiency of added N is often less than 50% because of poor management and higher rates of application, particularly in developing countries. The surplus N once released into the environment contributes to the soil, water, and air pollution, many health issues, loss of biodiversity, and climate change. Nitrous oxide (N_2O) is a potent greenhouse gas that has 296 times higher global warming potential and about 80% of this gas is released from the agricultural fields where N is applied. Slow or controlled release of N fertilizer can improve its use efficiency and decrease its environmental impacts. In this study, we evaluated the N_2O emission from Zn fortified nano-bentonite coated (*Zbento-Urea*) and ZnO NPs coated urea (*Znano-Urea*) in silty clay and sandy loam soils with crop and without crop. We also evaluated the effect of the method of fertilizer application on N_2O emission i.e., surface placement and deep placement. The emission of N_2O from coated urea was compared with the N_2O emission from conventional urea. The soil without fertilizer application was considered a control. The static chamber method was used for N_2O flux measurement. N_2O emission was measured from bare soil continuously for 15 days after the application of fertilizer by using an N_2O analyzer (*Thermo Fisher Scientific 46i, USA*), while from planted soils the N_2O flux was measured continuously for one week after fertilizer application and then twice a week. The results showed that coated urea significantly reduced the daily N_2O flux intensity as compared to conventional urea. A significant delay in the N_2O emission was also observed. The N_2O emission calculations from the planted soil experiment showed that during the application of the first dose there was no difference in the emission of N_2O from coated and uncoated urea while the N_2O emission from coated urea was reduced significantly when the second dose of fertilizer was applied. Deep placement of fertilizer reduced the emission of N_2O from silty clay soil while it has no effect on N_2O emission from sandy loam soil. It was concluded that the use of the enhanced efficiency Zn coated urea with appropriate soil management practices can reduce the emission of N_2O from agroecosystems.

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Different stages NPK evaluation of a slurry treatment plant in a 3000 sow industrial scale production farm

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The pig slurry, without any treatment, can become an N ammonia emission source. There is plenty of laboratory research done about the emission reduction process. In this work, we have evaluated a slurry treatment in a 3000 sows industrial scale plant.

The slurry treatment is made with a solid liquid separation (with 200μ holes diam), an SBR (Sequencing Batch Reactor) with nitrification denitrification cycles (NDN), ending with an effluent decanter.

A 13000 m3/year of lactating sows slurry has been treated. This slurry agronomic value is really low with 98%+1,2% humidity, less than 1,65% SST, Total N between 1,84 to 2,14 kg/m3, 60 - 80% N ammonia, a 0,45+0,3 kg/m3 P, and 1,12 kg/m3 K.

For a period of almost 2 years, every 3 moths an analytical control of every stage of the treatment was done in order to study the different process performance. Three samples were taken in each sampler point.

The Total N content has been reduced by 97% in an annual in global basis. Moreover, there is a 23% reduction in the solid liquid separation, a 64% decrease in the SBR process, and a 90% reduction in the final effluent decanter. Also, DQO falls from 23995 to 865 mg/lO_2. There is at least a 90% efficiency even during the low temperatures' months, with an average minimum Temperature of -1ºC, (average monthly temperature variation between 3 and 21ºC).

The Spanish Ecological Transition Ministry sponsors some projects buying CO_2 Tn from those farms that achieve a least a 65% N reduction. The global process evaluated exceeds this efficiency.

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Chances and challenges to improve Polish inventories of ammonia emissions from livestock systems

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National emission inventories serve as valuable source to monitor air pollution, identify major emission sources as well as to develop reduction targets and assess relevant mitigation options. In Poland, ammonia emissions mostly derives from agriculture with significant share of manure management from livestock and use of organic fertilizers to the agricultural soils. Hence, high quality country-specific data are required to reduce considerable uncertainty in emission compilation resulting from default values. Particularly, one of the most valuable parameters are "emission factors" (EF) that describe the emission rates from each of activities. However, depending on the goals of individuals studies scientific outcomes often are reported in different units which hinders comparisons of quantitative impact of these practices on air pollution. The purpose of this work was, therefore, to compile and review experimental data on ammonia emissions from various livestock systems, including different mitigation options, carried out for Polish conditions. The source of information were: scientific literature (publications in peer-reviewed journals, monographs, chapters in monographs, doctoral dissertations, published post-conference materials) covering the period of 2000-2021. In total, 33 publications were found where experimental results of ammonia emissions were reported. A critical review of the available literature identified 14 different technologies or practices that were tested to estimate their effectiveness in reducing ammonia emissions. Additionally, our research served as an input to the database DATAMAN with agreed quality criteria enabling conversion to EF (Webb et al. 2021). As a result of our compilation, 47 observations with EF were incorporated into the database. Our compilation also showed that relevant set of published results neither contained data on emission factors nor conversion to EF was possible due to missing information on, e.g., manure type, nitrogen content in excreta or manure, number and type of animals, duration of the experiment. Our analysis indicate that experimental emission data can be successfully utilized for inventory compilation. There are, however, still challenges in providing simultaneously several key parameters which are essential for proper estimation of EF in Polish conditions.

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The carbon footprint per liter of milk is explained by NUE

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The percentage of nitrogen (N) recovered in milk relative to that ingested in dairy cows (NUE_{VL}) varies from 15 to 35% (Uwizeye, 2019). This efficiency can refer to the milking cows or to the total number of animals on the farm (NUE_{CR}). Both NUE_{VL} and NUE_{CR} are not environmental indicators per se, but they do reflect to the N losses (NO_3, N_2O and NH_3) included in the life cycle analysis for the calculation of the carbon footprint per liter of milk. The aim of this work is to analyse at farm scale the possible relationships between NUE_{VL} and NUE_{CR} with the total carbon footprint as: [CH_4+CO_2+N_2O+CO_2 soya+CO_2 iLUC (Indirect Land Use Change)-Carbon sequestration] of five dairy farms feeding typologies. These were classified as "Organic, O", "Grazing, G", "Grass silage, GS", "Maize silage, MS" and "Grass and maize silage, GMS". The DairyCant (Salcedo, 2015) was used. Results indicated average intakes of 489±103 g N VL day; 29.8±5.9% for NUE_{VL} and 22.7±5.9% for NUE_{CR} and a carbon footprint of 1.085±0.30 kg CO_{2e} L^{-1} ECM (fat-corrected milk). Among typologies, the highest VL N intake per day, NUE_{VL} and NUE_{CR} were located in MS ($P<0.05$), with means of 587±79 g N; 33.1±4.3% and 26.5±4.4% respectively, and the lowest of 390±86 g; 25.7±5.7% and 17.1±5.1% in O. In contrast, the carbon footprint per liter of milk was lower in MS ($P<0.05$) and higher in O, with averages in each case of 0.97 and 1.27 kg CO_{2e}. NUE_{CR} and NUE_{VL} for the data set (n=54) explained 61% and 30% respectively of the variability of CO_{2e} L^{-1}, the equation being of the type: 1.99 - (0.04 NUE_{CR}); ±0.19 r^2=0.61. The simulated values were 1.08 kg CO_{2e} L^{-1}. The simulation of the carbon footprint with the variable NUE_{CR} was acceptable, as is evident from the positive values of the model efficiency (EF=0.61) and greater than zero and a high clustering index (d=0.86). The positive sign of the mean bias error (MBE=0.23) indicated overestimation and a low root mean square error percentage (RMSE=0.33%). In conclusion, we note that the use of NUE_{CR} as an independent and low-cost variable can explain the variability of the carbon footprint per liter of milk.

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Effects of grazing XTriticosecale with Manchega sheep on N_2O emissions

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Faeces and urine are livestock grazing main sources of Nitrous oxide (N_2O) emissions. Grass concentrations of proteins (CP) and water-soluble carbohydrates (WSC) might be useful to mitigate such emissions, just by enhancing Ammonia (NH_3) sequestration for the synthesis of microbial protein, what could be achieved by raising the recovery of Nitrogen (N_2) in milk. The conversion of Feed-N into Milk-N (Nitrogen Use Efficiency, NUE) could be indirectly used to estimate it. This parameter is affected by the capture of N at rumen level, the protein degradation process and the synchronisation of WSC and CP supply on microbial protein synthesis. This work analyses the feasibility to reduce N_2O emissions in Manchega sheep breed when moving from an animal feeding system based on the usage of alfalfa hay (AP_e, year 2019) to other based on grazing on XTriticosecale (AD_i, 2021-22 period), by assessing milk urea concentration, WSC intake and NUE. ManleCO$_2$ was the simulation model used to estimate N_2O emissions (Salcedo et al., 2022). Results showed higher concentration of WSC and higher WSC/CP ratio in XTriticosecale based feeding (17.5% and 1.05), compared to alfalfa hay based feeding (11.2% and 0.50). In terms of CO_2 equivalents, N_2O in milk decreased from 326 grams per liter in AP_e to 243 grams per liter in AD_i ($P<0.001$), and urea concentration in milk decreased from 0.59 grams per liter in AP_e to 0.49 grams per liter in AD_i ($P<0.001$). No significant differences were found in NUE between both feeding systems (11.9% and 13.4%, respectively). WSC intake (in terms of grams per ewe and day) and NUE are negatively correlated with N_2O emissions per liter of milk (r^2=-0.62 and r^2=-0.41, respectively; $P<0.001$) in both cases. Such differences could be attributed to the enhancement in microbial protein synthesis in AD_i (+ 53 g per ewe and day), that was indirectly estimated according to Oldick et al. (1999), that considers net energy intake from milk as an independent variable. In conclusion, ESC intake and NUE might be useful variables for the estimation of N_2O emissions per liter of milk in Manchega ewes grazing on XTriticosecale grasslands in spring time under Mediterranean climate conditions.

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Exploring the pathways for nitrogen losses from sheep urine patches between upland and lowland grazing systems.

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Urine patches from livestock present unique environments where extreme nitrogen (N) loading occurs, the average N load from a urination event is between 500 to 1000 kg N ha^{-1}. N losses from urine include nitrate leaching, plant uptake, ammonia volatilisation, and nitrous oxide, nitric oxide and nitrogen emissions. Urine patch N losses have been extensively researched for cattle excreta on lowland pastures under intensive management, however, few studies have been undertaken in extensive sheep grazing systems in temperate climates. Upland pastures vary greatly in vegetation, topography, climate, soil, management and productivity compared to lowland grazing systems. These factors can all affect how N is cycled in soils. The reported default N losses from urine patches do not take into account the potential differences to N cycling and N losses from these different grazing systems. To address this a mesocosm experiment was conducted exploring N losses from three sites along an altitudinal gradient including one lowland site (Cambisol) and two upland sites (Podzol and Histosol). The sites varied in soil pH and organic matter content, vegetation, microbial community, nutrient inputs and management. The study measured greenhouse gas emissions, potential ammonia volatilisation, N leaching, plant uptake and microbial immobilization from intact soil cores over a 13-week period in which half of the cores received artificial sheep urine and the remainder received the equivalent volume of water. Data from previous field studies have shown that nitrous oxide emissions and emissions factors from the two upland sites are much lower than the lowland site (Marsden et al. 2018, 2019), indicating differences in N cycling in the upland urine patch. This experiment is expected to show that the other N loss pathways also vary when comparing upland and lowland urine patches, addressing a crucial knowledge gap for livestock farming systems. Through improving the understanding of N losses from urine patches this can provide more realistic, regional, and accurate emission factors for upland farming systems.

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Nitrogen and carbon excretion from beef cattle grazing two sward types in South West England.

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Nutrient excretion from grazing animals is a major part of the farm nutrient cycle but it is challenging to accurately measure, especially under field conditions when animals are freely grazing. To make accurate measurements, two field campaigns were carried out in 2021 to estimate N and C excretions via urine and dung deposition from beef cattle (n=30) when grazing either permanent pasture (PP, dominated by *Agrostis stolonifera* L. and *Lolium perenne*) or a *Lolium perenne* L. (cv. Abermagic, high-sugar grass) and white clover mix sward (HWC) on the North Wyke Farm Platform, in Devon, UK. In each pasture, the individual animal dry matter intake (DMI) and the fecal output (n=15) was estimated by the C32-alkane tracing technique (C32/C33 ratio) and the daily volume of urine excretion was estimated using the creatinine content. The urine and dung samples were collected for each animal twice a day from the 8th to the 12th day of n-alkane dosing in June and August 2021. Samples collected during each campaign were analyzed for total N and total C (dung, grass, and urine), n-alkane (dung and grass) and creatinine (urine) contents. Animal live weight (LW), herbage mass and botanical composition were recorded. The estimated DMI was similar between sward types with values for PP and HWC of 11.9±0.53 and 10.2± 0.23 kg DM day^{-1} in June and 11.4±0.61 and 11.1±0.44 kg DM day^{-1} in August, respectively. The fecal excretion was 8.8±0.84 and 7.2±0.42 kg DM day^{-1} in June and 7.1±0.76 and 9.3±0.74 kg DM day^{-1} in PP and HWC, respectively. The volume of urine excreted was similar between pastures in June (19.5±2.25 and 21.7±2.57 L day^{-1} in PP and HWC, respectively) whilst in August the excretion was higher in HWC than in PP (23.3±2.35 versus 45.9±4.35 L day^{-1}). These and coming up results will ensure a more thorough understanding of farm nutrient cycling and allow nutrients to be properly managed with losses or accumulations in excess avoided.

Influence of feeding regime on ammonia emission from dairy slurry applied to Galician pasture

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Nitrogen losses can account for substantial amounts of crop available N, mainly by ammonia emission, that occur mainly during manure management and N fertilizer application to agricultural land. Application of organic fertilizers to crop is recommended as a way of supplying the essential nutrients for plant growth, recycling nutrients within the agricultural systems, while reducing the need for inorganic fertilizers. There is a lack of knowledge about ammonia emissions from slurries from different dairy cows feeding systems in Galicia as well as slurry treatments at region scale. Thus, ammonia emissions from different dairy slurries applied on undisturbed soil plots with clover and reygrass crop, were measured using acid traps. In this study we compared the differences between ammonia emissions from the different feeding systems (classified according to the main forage in pasture grass: PG, grass silage: GS, corn silage: CS or combined grass/corn silage: GCS) and compared these results with urea fertilizer. Also, slurry acidification and the mixture of slurry with urea were considered with the aim to look for strategies to reduce the N volatilization, leading to eight treatments with different N fertilizers, and ammonia emissions were measured during 9 days. 0.5 g of total nitrogen in all treatments were applied on first day. The highest ammonia emissions were observed in mixture of slurry with urea and in urea fertilizer (with 83.6 mg per plot). The highest emission per hour was observed in mixture of slurry with urea and in urea fertilizer (12,7 mg and 10.6 mg per hour, respectively). There were no differences between the GS, GCS, CS slurries and the acidified slurry, showed the lowest ammonia emission (30.88 mg per plot and 6.18% of total N applied). Only acidified slurry was lower in terms of fluxes compared with GCS slurry (3.43 vs 5.66 mg per hour). Ammonium emissions were lower in the PG slurry, being significantly lower from GCS and CS slurries (15.61 vs 36.28 mg per plot, 2.52 vs 5.51 mg per hour and 3.12 vs 7.26%, respectively) and without differences between the other slurries, including slurry acidified. No differences were found between the emission of PG slurry with the control treatment. Preliminary results indicate that slurries have low ammonia emissions compared to urea, with few differences on this when slurry were acidified, especially highlighting the lower emissions achieved with PG slurry that could be related with lowest dry matter and N ammonia content, leading to a greater absorption of N available by the crop.

Nitrogen cycle regulation and associated ecosystem services in the context of climate change: assessing the potential of agroforestry in Brittany

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Excess of reactive nitrogen threatens our ecosystems by altering soil, air, water quality and biodiversity. Especially, nitrogen losses to water streams are of great concern for territories that are specialized in livestock farming. In the near future, it is expected that such losses will increase under extreme events as a consequence of climate change. Agroforestry - whereby trees are integrated on a plot with crops and/or livestock - is considered as a lever to increase the resilience of agroecosystems facing climate change by intensifying ecosystems services and supporting productivity. In livestock areas, tree-crop associations could prevent nitrogen losses through the impact of trees on microbial driven processes, nitrogen acquisition and water drainage.

This study aims to explore the potential benefits of agroforestry systems to improve nitrogen cycle regulation and associated ecosystem services within dairy farming systems in Northwestern France. As delivered ecosystem services are driven by ecological processes, we first explore the impact of trees on a key process driving the production of reactive forms of nitrogen, the nitrification. Nitrification is a microbial driven process and its stability varies according to different environmental conditions. In our study, impact of trees on nitrification stability - i.e. the biological response of nitrifying microbial communities to extreme climate events - is assessed through the use of a causal conceptual model linking field and lab measurements on trees, soils characteristics, practices and nitrification. These results will help us to fit a nitrogen cycle model to evaluate nitrogen losses at the plot scale in the context of climate change.

First field experimentations showed variations of soil properties, including soil nitrogen, according to two studied factors: (i) the distance to the trees; and (ii) the agroforestry design – as plots with alley-cropping agroforestry and hedgerows were studied. These first results call for the assessment of the delivered ecosystem services associated to the nitrogen cycle at farm and territory scales according to the potential development of these two agroforestry designs. To test this, results from the nitrogen cycle model will be nourished and complemented by data collected on farms through interviews. Later on, we plan to scale-up the assessment at territory scale by using a participatory design of agroforestry development scenarios.

The novelty of the hereby presented study is (i) to combine field, lab and modeling to assess the nitrogen cycle regulation at different scales and (ii) to consider its operational potential for building bridges between research, territorial development and field work.

Ammonia and nitrous oxide losses from intensive dairy cattle farms in the Basque Country (northern Spain)

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European dairy farming ranges from roughage-based systems to feeding regimes with large use of concentrates. Nitrogen use efficiency at farm level decreases as the animal production is intensified. The objectives of this work were to study ammonia (NH_3) and nitrous oxide (N_2O) losses from intensive dairy farms in the Basque Country, and to assess the abatement potential of different mitigation strategies.

13 pilot farms were assessed at farm-level for NH_3 and N_2O emissions. Herd, nutrition and manure management data were collected through surveys. Mean concentrate intake was 4,500 kg/cow/year, maize silage accounted for 55% of forage in milking herd ration, and milk yield was 12,730 kg/cow/year. Mitigation strategies were simulated on a standard dairy farm: 143 milking cows, 111 replacement herd (calves and heifers), 35 kg milk/cow/d, uncovered slurry pit and splash-plate slurry application. The following scenarios were simulated: (i) adjusted N intake (from 18.5 to 17.0 g N intake/kg milk), (ii) lower replacement rate (-20%), (iii) extending grazing period of dry herd and heifers (from 4 to 9 months), (iv) slurry pit covers, (v) slurry band spreading, and (vi) the combination of the strategies. All farms were simulated by using EMEP-EEA (2019) and IPCC (2006) software for NH_3 and N_2O losses, respectively.

Ammonia losses from the pilot farms ranged from 61 to 429 kg NH_3/ha, and averaged 183 kg NH_3/ha. Emissions represented from 18% to 42% of total N excreted. Nitrous oxide losses ranged from 6.9 to 28.8 kg N_2O/ha, with a mean value of 14.4 kg N_2O/ha. Nitrous oxide emissions accounted for from 2.0 to 2.5% of excreted N. Regarding the abatement scenarios, gaseous N losses from the default farm were 229 kg NH_3/ha and 14.0 kg N_2O/ha. Most promising NH_3-abating strategies were band spreading (-15.3%), N intake fitting (-10.1%) and covers (-8.8%). If all the strategies were simultaneously used, we estimated that NH_3 emission would be reduced by 38.8%. In terms of N_2O losses, reducing N intake (-8.4%), and the lower replacement rate and slurry band spreading (-2.0%) were the most promising strategies. We estimated that applying all the strategies, N_2O losses would be reduced by 10.6%. According to these results, it is suggested that if all mitigation practices were applied at the default farm, ≈ 5,000 kg N/year would be saved from the atmosphere, mainly from NH_3 reduction.

We conclude that intensive dairy farms from the Basque Country have significant room for improvement in terms of reducing NH_3 and N_2O losses. Nutrition, herd and manure management strategies may significantly contribute to reduce such losses, although their real implementation on-farm will depend on the required investments.

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Dynamic Quantification of Greenhouse Gas Emissions N_2O in Natural Wetlands

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Despite their less than 3% of global land area, wetlands are recognized among the world's most productive and valuable ecosystems since they constitute a zone of transition between aquatic and terrestrial environments. In fact, these wetlands are considered as hotspots that favorize the conditions for Nitrate removal via denitrification. Denitrification phenomena is defined as a stepwise reduction of Nitrate to Nitrogen gas carried out mostly by anaerobic bacteria. Unfortunately, denitrification contributes, to a certain extent, to potent greenhouse gas emission N_2O in case of incomplete reduction. However, assessing the magnitude of denitrification in wetlands is a miserable process due to the diversity of the factors influencing denitrification in terms of time and space and the diversity of methods and models suggested in literature to measure this process. In this study, we addressed different challenges in quantifying denitrification in natural wetlands and we suggested a dynamic quantification which is inclusive of different factors influencing the process.

Keywords: natural wetlands, denitrification, Greenhouse Gas Emissions, quantification

Cost-effective strategies to reduce of ammonia emissions from livestock production: A multi-country assessment

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Estimating costs and savings is an important step for finding prioritizing emission reductions, and assessing the economic impact of mitigation measures. Livestock production systems across countries and continents vary widely, hence also the available strategies to reduce ammonia emissions may vary considerably. Additionally, another important factor influencing national strategies is the target value for emission reduction set either by international agreements or national policies. This work aims to summarize current knowledge on costs and benefits associated with selected abatement measures to reduce ammonia emissions from livestock systems in six European countries and in Chile. The focus of ammonia reductions is put on feeding and manure management. Further, the cost-effective strategies of mitigation options are selected and compared among the case study countries. For instance, preliminary results indicate that in countries with dominating dairy production (e.g. Ireland, Poland), the most beneficiary mitigation options in terms of ammonia reduction are associated either with lowering of crude protein content or precise balanced diet with rumen non-degradable proteins. For Polish conditions its reduction potential of ammonia emissions is relatively low compared to other – slightly more expensive - feeding option, like extended grazing, whereas in other countries this option has lower potential. The multi-country assessment allows to highlight the similarities and differences between the case study countries in environmental and economic priorities and to understand the choice of strategies.

Improving Nitrogen Use Efficiency in Oceania: Policy Advice from Social, Scientific and Technological Perspectives

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Oceania is a highly diverse region in view of its geography and socio-economic development as well as agricultural practices. We can therefore expect that policy responses to increasing nitrogen use efficiency (NUE) will vary greatly across the region. Given that the economies of the Pacific are highly reliant on natural resources, degradation that is caused by N pollution will have a direct impact on sectors such as tourism and fishing. With this in mind, we aim to firstly analyse the current effectiveness of nitrogen use policies in the region from both quantitative and social perspectives. This will be undertaken at multiple scales using existing regional and globally collated data from individual countries and industries, as well as NGO's, UNEP, FAO, UNESCO. We will then evaluate the effectiveness of technological advances that may aid in improving NUE and contribute to proposing policy solutions for specific regions, with viability of adoption assessed through farmer and industry interviews.

Understanding and optimizing agricultural nitrogen utilization for synergies of UN 2030 SDGs

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Synthetic nitrogen (N) fertilizers have nourished half the global population by increasing food and feed production during the past century. However, over 60% N used along the food production chain was lost to the environment, threatening the environmental quality and human health. Almost all the UN 2030 Sustainable Development Goals (SDGs) are directly or indirectly related to N use and loss. It is essential to explore managing agricultural nitrogen for the maximum synergies among SDGs. This project intends to use literature review, model simulations, and environmental effect assessment to 1) map synergies and trade-offs between N and SDGs; 2) quantify the contribution of nitrogen in global SDGs through connecting SDGs by their N inter-linkages, and 3) explore ways to achieve synergy among multiple global SDGs through nitrogen management. The project is important for providing policy support for N management and achieving synergies among SDGs.

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Getting integrated nitrogen management into policy and practice - perspectives from UK and Africa

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This paper presents the results from three projects that assessed the nitrogen (N) issue at different scales and from different perspectives. It considers the potential for linking integrated nitrogen (N) management to policy development. The first project compiled and synthesized examples of good practice to inform more integrated and efficient nitrogen use in mixed arable and livestock farming, with a focus on the county of Yorkshire in the UK. The second assessed the package of policy responses required for integrated N management at UK scale, from agreeing global priorities to introducing national nitrogen budgets and targets to guide action to halve nitrogen waste by 2030 (Hicks *et al*., 2022). The third, developed a new model that integrates assessment of agricultural systems on (i) human health indirectly through dietary, obesity and malnutrition health risks from food consumption, (ii) human health directly through exposure to air pollutants from agricultural emissions, and (iii) greenhouse gas emissions (Malley *et al.,* 2021). The model has subsequently been applied in an Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa.

Implications of these three distinct studies for integrated N management at different scales and situations are presented in the context of achieving the goals of the UNEA Resolution on Sustainable Nitrogen Management.

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How to address Nitrogen waste abatement in the SUDOE territory: A co-creation approach based on the experience of three workshops

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Mitigating Nitrogen waste is a challenging issue due to the involvement of contrasting actors and interests. With this work we aim to get a collective vision of the challenges and opportunities regarding Nitrogen abatement within the Garonne and Tajo waters. In the first semester of 2022, we carried out three workshops in Spain, France and Portugal with different actors to discuss the situation of agriculture in the Garonne and Tajo basins. These workshops were based on the Fuzzy Cognitive Maps Methodology (FCM). Fuzzy Cognitive Maps are models (diagrams) that are built with groups of actors and show how an individual or a group conceives a given system or environment. The system is represented by nodes that are the factors that determine the system and arrows that represent the relationships/influences between these, whose intensity can be measured. In general terms, after the three workshops were successfully carried out, it can be said that the most recurrent problems or factors related to agriculture among the actors who attended the activities were those related to profitability issues in agriculture and the use of water in agricultural activity.

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Nitrogen Use Efficiency in Cropping Systems and Beyond

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In the pursuit of sustainable nitrogen (N) management, growing efforts have been devoted to quantifying and understanding N Use Efficiency (NUE) for a wide range of systems and on multiple spatial scales. However, differing definitions and quantification methods for NUE can potentially lead to misinterpretation or confusion by stakeholders, and consequently hinder comparisons among studies and experience sharing among researchers and regions.

To address this knowledge gap, we first focus on the definition and quantification of NUE for cropping systems. We investigated the theoretical differences, as well as connections, among three major methods for N use efficiency (NUE) quantification (i.e., N difference, ^{15}N tracer, and N budget methods). The investigation revealed the influence of soil legacy effects and offered recommendations for selecting the proper approach (Quan et al., 2021). Focusing on the N budget method, we led the first-of-its-kind inter-comparison project for NUE and N budgets on a national scale, involving 10 major research groups (Zhang et al., 2021). We identified the most uncertain N budget terms by country, many of which range as widely as their median, and recommended approaches for improving estimates and reducing uncertainties.

Moving beyond cropping systems, NUE has been quantified for a wide range of systems based on the N budget method. Through a literature review, we synthesized existing N budgets under a framework with five systems (i.e., Soil-Plant system, Animal system, Animal-Plant-Soil system, Agro-Food system, and Landscape system) and four spatial scales (i.e., Plot and Farm, Watershed, National, and Global scales). Based on the system definition, global NUE drops from 43% for the cropping system (a Soil-Plant system) to 16% for the Agro-Food system, demonstrating large efficiency loss beyond crop production (Zhang et al, 2020). Assessing NUE at various system and spatial scales can help to unpack N challenges and identify management gaps (Li et al., 2019).

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Towards a global nutrient budget data platform

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Accurate estimates of nutrient inputs and outputs on agricultural land at national and sub-national scale are critical for (i) quantifying nutrient balances and nutrient use efficiency, (ii) assessing the impact of nutrient use on food production, biodiversity, global climate, water and air quality and other environmental functions, (iii) developing realistic nutrient and emissions targets and roadmaps, and monitoring progress towards them, and (iv) forecasting future fertilizer demand. Such data are of particular importance for national action plans on SDG Target 2.4 (sustainable food production systems, including in the context of climate change). Various national and sub-national scale databases on nutrient inputs and outputs have been created by organizations and researchers worldwide. They have resulted in coarse and widely ranging estimates because of large uncertainties due to data scarcity and differences in data sources and estimation methods used. The accuracy of many data layers remains poor in many countries. Persisting data gaps are difficult to fill with the current methods and the resources available. An improved dataset will result in stronger evidence base for use by a wide range of stakeholders, including policy makers.

Here we first review the current status of data on nutrient inputs and outputs on agricultural land in the world and we discuss major trends as well as knowledge gaps. We then present a vision and strategy for a coalition to create and manage a joint nutrient budget data platform that brings together data and expertise available in public and private sectors. We discuss the general framework and principles to follow, including distributed co-creation, collective ownership, openness and innovation in creating novel data sourcing pipelines and analytical tools. The joint platform, a test version of which is being built for dissemination in FAOSTAT and IFASTAT, will lead to more timely and better aligned reference data, reduced uncertainty, and increased granularity in terms of sub-national and crop-specific data. Novel data collection methods will focus on acquiring better agronomic information at a suitable aggregation level, including data on fertilizer use by crops, manure use, crop residue management, crop biological fixation, etc. The basic data collection will be complemented with existing and emerging datasets from top-down measurements such as remote sensing.

Filling critical data gaps through a collaborative effort will greatly enhance use of global nutrient data for specific policy and investment purposes. It will enable countries to better monitor and report on nutrient use, nutrient use efficiency, risks, and emissions from agriculture.

Nitrogen in irrigation water sources: the missing link in the agricultural nitrogen cycle and related policies in Europe

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Irrigation is one of the 28 agri-environmental indicators defined in the European Union Common Agricultural Policy. The scope of this indicator fails, however, to consider irrigation as an additional source of nitrogen (N), which is often a missing link in agricultural N budgets. The annual N input from irrigation water sources (N_{Irrig}) was quantified for Europe for 2000-2010 at a resolution of 10x10 km, accounting for crop-specific gross irrigation requirements (GIR) and surface- and groundwater nitrate concentration. GIR were computed for 42 crops, while spatially explicit nitrate concentration in groundwater was derived using random forest (R^2 = 0.65 ± 0.08). Irrigation requirements were relatively stable during this period (51-60 $km^3\ yr^{-1}$); about 62% of irrigation requirements were located in Mediterranean countries. Those data were compared with 4 models, attaining strong correlations (R^2 = 0.87-0.90). The N_{irrig} in Europe increased over the 10-year period (181 to 241 Gg N yr^{-1}), approximately 68% of which occurred in the Mediterranean region. The main hotspots appeared in areas with both high irrigation requirements and high groundwater nitrate concentration, in the south of Portugal and Spain, and the eastern coast of Greece where N_{Irrig} reached up to averaged values of 129 kg N $ha^{-1}\ yr^{-1}$. Smaller hotspots were identified in the Netherlands, Sweden and Germany. Our data showed that by not including N_{Irrig}, environmental and agricultural policies are likely underplaying the real extent of N pollution hotspots in European irrigated systems. However, it is likely that the overall magnitude of N_{Irrig} is overestimated due to the unaccounted recycling of N in ground- and surface water at the spatial and temporal resolution used.

Nitrogen balance in smallholders' maize cropping systems in Kenya.

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Soil Nitrogen (N) mining is a serious threat to sustainable production of maize, a staple crop for food security in Kenya. By integrating data collected from farmers' fields, experimental plots, and mass balance calculations, this study reveals the extent of soil N mining for different categories of farmers. It also provides practical solutions and opportunities for improving the management of N. Our data show that most maize farmers within the Lake Victoria region have NUE values >90%, low N inputs < 50 kg N ha^{-1}), and yield below the target potential of 5 t ha^{-1}. Our findings showed that increasing N fertilizer application in maize cropping systems could optimize NUE to fall within the recommended range of 50 to 90%. In N balance, deficits ranging from -66.6 kg N ha^{-1} to -125 kg N ha^{-1} were recorded among fertilized and unfertilized plots. In addition, unbalanced N fertilization in farmers showed a trend below the linear neutrality option for good N management in maize crops. From the experimentation involving some scenarios of N use, it was revealed that with the increase in N application by farmers, there is a likelihood of improving N balance. However, the current and recommended rates are insufficient and will require the integration of nature-based sources of N to optimize N availability and the sustainability of the maize farming systems in Kenya.

Keywords: soil mining, unbalanced fertilization, partial N balance, soil fertility,

SUSTAINABLE NITROGEN MANAGEMENT IN SOUTH ASIA; DRIVERS, TRENDS AND WAY FORWARD

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Nitrogen is responsible for about 48% of global food production and is a key to life on this planet. The nitrogen fertilizer use has been increased tremendously during the last 5 to 6 decades which has also resulted in many of the serious environmental concerns like deterioration of water and air quality, biodiversity loss, and climate change. Sustainable nitrogen management is linked to many of the sustainable development goals. As nitrogen pollution has already crossed the planetary boundaries, a holistic and joint-up approach is needed for its sustainable management. South Asia is one of the global hot-spot for N emissions. South Asia occupies about 5.7% of the world's land surface area with about 24.8% of global population, thus has tremendous pressure on ecosystem services which are already under severe pressure due to air pollution, depletion of water quantity and quality, changes in land use and soil degradation. The overall N use efficiency in the region is seriously low (about 45%) which further warrants to devise and adopt strategies aiming at reducing N waste. Many of the available policies in these countries are directly or indirectly linked to nitrogen management. There is dire need to assess the available technologies and devise joint and holistic strategies to strengthen the institutional and regulatory frameworks, to address the N challenge. This requires modernization of practices and procedures involved in N production and consumption, encompassing all relevant sectors including agriculture, livestock, transport and industry to reduce N leakage to the environment and increase NUE.

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Some lessons learned about the use of water and nitrogen in vegetable crops

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During the last 7 years, within the framework of projects Riego-Asesor, Phertilizer and "Fertirriego de precisión para un manejo sostenible de la horticultura intensiva. Aspectos agronómicos e implicaciones ambientales" we have conducted multiple open field trials in the Campo de Cartagena and multiple greenhouse experiments in Santomera (Murcia), either in pot or hydroponic. The trials with vegetable crops include endive, baby lettuce, romaine lettuce, summer wonder lettuce, Iceberg lettuce, piel de sapo melon, and potato. The overall objective of all these projects was to make a more efficient use of two mayor resources used in agriculture; water and nutrients, with special focus on nitrogen. Here we resume the most notable results of these experiments; i) the amount of irrigation water applied by farmers was tightly adjusted and this amount closely mimics the FAO recommendations and custom-made water balance model named "Riego-Asesor", ii) a fertigation strategy aimed to match water and fertilizer inputs with plant demand is key in improving water and nitrogen use efficiency, and simple to use decision support system was designed for this goal iii) irrigation frequency/dose plays a critical role in improving water and nitrogen use efficiency, with high frequency of irrigation resulting in higher yield and lower nitrate leaching iv) knowing how the nitrogen source (nitrate/ammonium) affects growth and development in different vegetable crops can be a further step of adjustment to increase nitrogen use efficiency. All this information can be used to designing fertigation strategies in intensive agriculture that match and integrate water and nutrients supplies with the needs of a given crop under a given growing conditions.

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Vermicomposting for improved N availability and the potential of vermicompost sources on N mineralization and soil biological properties on Nitisols

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Vermicomposting converts organic wastes into high-quality nutrient-rich compost and has been considered as a suitable technology for developing countries, especially at the household and community level as it is a simple and natural technology that does not require sophisticated machinery and frequent process monitoring. In addition, attempts to address SOM and nutrient losses in a sustainable manner in sub Saharan Africa countries require careful optimization of use of organic amendments such as through vermicomposting. We performed a vermicomposting experiment using three-earthworm species, exotic (*Eisenia fetida* and *Eisenia andrei*) and indigenous (*Eudrilus eugeniae*), fed on six different substrates made from agricultural wastes (cow and donkey manure separately spiked with three types of equally mixed crop residues (maize with soybean (MS), maize with banana (MB) and soybean with banana (SB)) to assess the nutrient stabilization in the resulting compost; and performed an incubation experiment using a selection of these vermicomposts to study the net N mineralization of the composts, and how they affected soil microbial properties such as microbial biomass C, dehydrogenase and β-glucosidase activities, in Nitisols. Earthworm activities during vermicomposting of agricultural wastes accelerated the rapid decomposition of mixed substrates and resulted with a significant reduction of TOC (C mass loss > 65%) and C:N ratios (twofold compared to the control without earthworm) and an increase in N mineralization and the total concentration of P, K and S. The effect of vermicompost on N availability and soil microbial quality significantly varied depending on vermicompost sources. The vermicompost made from cow manure mixed with soybean and banana residues using *Eudrilus eugeniae* had the highest net N mineralization (32.4 μgNg^{-1} soil, 75% of N added). Regardless of vermicompost type, amended soils had significantly higher microbial and enzymatic activities than unamended control. Our results suggest that vermicompost sources tested could reliably use for long-term improvement of soil nutrient mineralization and microbial activity under Nitisols of Ethiopia due to their greatest microbial activities and nutrient dynamics during vermicomposting.

Potential Benefits and Costs of Using Nitrogen Fertilizer to grow Irrigated Cotton in Australia

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The focus in this paper is on estimating the addition to the global social cost of increasing carbon dioxide content in the atmosphere that is legitimately attributable to emissions of nitrous oxide from the nitrogen fertilizer used to produce fully irrigated cotton in Australia. Much is known about the technical and economic elements of nitrogen use in crop systems and the quantities of nitrous oxide as a pollutant from cropping systems, while the market price of carbon dioxide emissions sets the size of the social cost of nitrous oxide emissions contributing to global warming. Starting from the farm, production economic theory is used to estimate the private and social benefits and costs of nitrogen used to grow irrigated cotton. The benefits of nitrogen used to grow fully irrigated cotton and the cost of the ensuing emissions of nitrous oxide are assessed in an economic framework of marginality, counterfactuals, opportunity costs and crop rotations. At farm level, using economic analysis, the marginal private and social benefits of using nitrogen to grow fully irrigated cotton in Australia far outweigh the marginal private and social costs of the nitrogen and the direct emissions of nitrous oxide.

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Costs and benefits of ammonia abatement in Australia

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The abatement of ammonia (NH3) emissions has attracted much attention globally given its increasingly dominant role in ecosystem sustainability and human health. The potential, costs and benefits of NH3 abatement in Australia, the driest inhabited continent in the world, are less known. We mapped the latest spatial-temporal NH3 emissions in Australia and assessed the feasibility of NH3 abatement. Results show that annual NH3 emissions in Australia ranged 1.2-1.4 Tg N yr-1 in response to agricultural activities and climate variability from 2014-to 2019. Intensive animal and cropping systems occupy ~13% of Australia's land but contribute 60% of NH3 emissions. The mitigation potential of Australian agricultural NH3 emissions is 32% (21-47%), with implementation cost estimated at 0.3 (0.1-0.9) billion US dollars (USD), equivalent to only one-tenth of the total mitigation benefit at 3.1 (0.5-7.6) billion USD. The societal benefits of mitigating NH3 emissions in terms of ecosystem sustainability (0.6-6.2 billion USD) are higher than human health benefits (0.8-1.9 billion USD) due to the small human population and the uniqueness and significance of Australia's biodiversity. Mitigating NH3 emissions in Australia should be prioritized in the animal and cropping systems to achieve the low-hanging fruit. Cost-effectiveness mitigation of NH3 will require integration with the current climate policy.

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Ammonia mitigation cost analysis for the German livestock sector

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Introduction

Under the EU NEC Directive and the UN CLRTAP Convention, Germany is obliged to reduce ammonia emissions by 29 % to an annual level of 444 kt by 2030. For this purpose, policy measures (here: NEC scenarios) have to be developed in order to realise a cost-efficient reduction national strategy.

Methodology

With this research work, we present a consistent cost calculation model for livestock farming in Germany. This was achieved by analysing existing investment data sets on livestock facilities and updating these using our own surveys and amending them. The model allows the ex-ante and ex-post calculation of ammonia (NH_3) abatement costs and the impact of ammonia mitigation measures on economic success variables at product, process and farm level. By blending individual farm data, specific NH_3 abatement costs, and structural data at the district level (which were derived from official statistics on agricultural structure) using regression analysis, we calculated the compliance costs for NH_3 abatement for different policy scenarios, both regionally and nationally and broken down by livestock category and housing system.

Results

With the calculation model, the mitigation impact and national compliance costs for the NEC Directive were determined for 5 policy scenarios. The baseline is representing the emissions in 2030 that will occur following the implementation of already existing legal provisions.Three of the five NEC scenarios we have designed are below the required NEC emission ceilings. These scenarios focus on techniques for the application and storage of liquid manure. The annual costs for these 3 scenarios range from 99,6 to 126,2 million €/year. The specific mitigation costs per kg of ammonia in these scenarios amount to an average of 1,30 to 1,65 €/kg ammonia abated.

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Abatement of agricultural ammonia emissions in Irish agriculture - development of a marginal abatement cost curve to 2030

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Agriculture is responsible for virtually all ammonia (NH_3) and N_2O emissions in Ireland. National NH_3 emissions are targeted to be reduced by 1% by 2030, while agricultural greenhouse gas (GHG) emissions must decrease by at least 22% by 2030. However, Ireland has exceeded its NEC Directive limits in seven of the last ten reporting years, while N2O has risen by 14% since 2011.

Although many management practices can abate NH_3 and/or N_2O emissions the challenge is to identify measures which deliver mitigation for both and in the most cost effective manner. One way to elucidate this is through calculation of cost-effectiveness metrics using marginal abatement cost curve (MACC) methodology. The aim of this study was to: i) assess the mitigation potential of a range of NH_3 and N_2O measures most relevant for a bovine dominated system of agricultural production, ii) estimate the uptake, efficacy, cost and subsequent cost-effectiveness of selected mitigation measures, iii) evaluate the cost-effectiveness and absolute effect of mitigation measures over a 10 year time horizon under different agricultural activity level assumptions, and iv) evaluate, if a combination of mitigation measures can bring Ireland into compliance with the EU NEC Directive whilst contributing to N_2O reductions.

Ammonia and N2O emissions were estimated using a static inventory model approach, based on emission factors applied to agricultural activity data. Activity data used in this analysis is based on projections from the FAPRI-Ireland Partial Equilibrium Model of the Irish agricultural economy. The emissions factors followed those used in the Ireland's national transboundary gas and greenhouse gas inventories. Mitigation measures for NH_3/N_2O abatement considered here were chosen based on a review of both national and international literature. Mitigation potential was assigned based on published national and international efficacy figures.

Thirteen measures were selected into the final MACC. Two measures provided the bulk of available mitigation potential for ammonia, with low emission slurry spreading (LESS) for bovine slurry delivering on average over 9.04 kt NH_3 per annum, and protected urea (urea with urease inhibitor such as N-(n-butyl)-thiophosphoric triamide (NBPT) (urea + NBPT)) delivering a further average of over 3.11 kt NH_3 per annum. Combining these two measures can deliver approximately 80% of the overall calculated mitigation potential. Mitigation of N_2O was calculated to be 1.9 $MtCO_2e$ per annum or one-third of national N_2O emissions. No single measure accounted for more than 20% of this abatement total, with optimizing pH, legumes and changing fertilizer type calculated to be the most cost-effective measures.

How nitrogen inhibitors keep agricultural yields & environmental policies on target

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Due to N losses in form of ammonia (NH3) and nitrous oxide (N2O) emissions as well as nitrate (NO3) leaching (and nitrogen (N) which is fixed in the soil) only 50% of the applied N is taken up by the crops. These losses have negative impacts on the environment (NH3: acidification of the soil, reduced biodiversity, forms with particulate matter smog; N2O: climate change; NO3: eutrophication of groundwater and waterbodies etc.) and so on the society (human life and health) as well as on the economics of a farm (payment for 100% N, reduced yield).

National governments as well as EU commission recognized such losses and established 30 years ago regulations (1991: EU Nitrates Directive, 2001: EU NEC Directive) to reduce them. One of the six priorities of the new EU commission (2019-2024) is the European Green Deal with the target to become the first climate-neutral continent by 2050 (milestone 2030: reducing net greenhouse gas emissions by at least 55%). For the agricultural sector the EU commission presented two strategies: Farm-to-Fork (F2FS) and Biodiversity (BS). One of the main targets in both strategies is the reduction of nutrient losses by at least 50%. The existing and upcoming EU regulations under the EU Green Deal will have a big impact on agriculture (farmers) and especially N fertilization. This affects the upstream (fertilizer producers, distributers and dealers) and downstream industries.

How can the targets of the EU Green Deal concerning N fertilization be reached without a significant negative impact on farmers and industry economics and provide safe supply of food and feed? By increasing nitrogen use efficiency (NUE) via a combination of tools/devices to determinate the optimal N amount and application of suitable products to reduce N losses.

Such suitable products are nitrogen inhibitors: urease inhibitors (UI) for urea containing fertilizers (reduction of NH3 emissions from pure urea by on average 70%) and nitrification inhibitors (NI) for urea and/or ammonium containing fertilizers (reduction of N2O emissions by on average 38% and NO3 leaching by on average 18%).

Model calculations show that nitrogen inhibitors could reduce fertilizers footprint by a third (32 mio tonnes CO2eq) if all mineral fertilizers consumed in one year in the EU would be treated with UI and NI, resp.. This amount is equivalent to removing 8.9 mio passanger cars driven of one year.

So nitrogen inhibitors are a triple win: For farmers (increased return on investment, simplified farm management, prepared for future regulations), the society (better air and water quality, reduced climate impact, improved biodiversity) and the industry (innovation, differentiation, prepared for future regulations).

Nitrogen fertilisation effect and ammonia emissions from field application of cattle slurry depending on slurry treatment and application strategy

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The fertiliser value of cattle slurry is often low, due to its high dry matter (DM) content, implying a high carbon to nitrogen ratio (C/N ratio), decreasing the availability of N through immobilisation. The high DM content also leads to slow slurry infiltration and potentially large ammonia losses after field application. The aim of this study was to investigate methods for improving the N fertiliser effect of cattle slurry in crop production. For this, the effect of reducing the carbon content in cattle slurry by solid-liquid separation or anaerobic digestion was investigated, as well as the additional effect from ammonia abatement strategies such as acidification and trailing shoe application of slurry. In total seven field experiments were conducted in winter wheat and grass ley in 2019-2021. The experiments were carried out at one clay soil (>40% clay) with cereal based crop rotation and no addition of animal manure, and one sandy loam soil with a crop rotation including both 3-4 years forage ley and annual crops, and frequent addition of animal manure. The experiments were two-factorial with the factors being slurry type and application strategy. The slurries tested were untreated cattle slurry (CS), the liquid fraction from solid-liquid separation of cattle slurry (LF), and biogas digestate (BD) mainly based on cattle slurry. Application strategies tested were trailing hoses, trailing shoes and trailing hose application of acidified slurries. Sulphuric acid (96%) was used for slurry acidification, with a target pH of 6.0 for all slurries. Average pH after acidification was 5.9, 6.1 and 6.7 for CS, LF and BD, respectively, with the average amounts of acid added being 6.7, 5.0 and 16.5 kg ton^{-1} slurry. Ammonia emissions, for the same treatments as in the fertilisation trials, were measured in separate field experiments in grass ley at the clay soil site, using wind tunnels connected to continuous online ammonia measurements, with a technique described in detail by Pedersen *et al.* (2020). Measured cumulative ammonia emissions (as percent of applied total ammoniacal nitrogen (TAN)), was highest for BD (32%), followed by CS (29%) and LF (23%). The highest initial emission rate was seen in BD (with highest pH), while CS (with highest DM content) showed the slowest decline in emissions. Slurry acidification effectively reduced ammonia emissions for all slurries (by 75-88%). For acidified CS, an unexpected increase in ammonia emissions was seen from about 48-70 hours after slurry application, indicating an increased slurry pH. This phenomenon is interesting and would need further study. For the fertilisation experiments, nitrogen use efficiency of slurry treatments in comparison to a mineral N fertiliser was calculated, as mineral fertiliser equivalents (MFE) in percent of applied TAN. Averaged over all experiments, the highest MFE with trailing hose application of non-acidified slurries was seen for LF (55%), and BD (51%). For CS it was lower (32%), probably as a result of the higher C/N ratio of CS (10.7 compared to 4.2 and 6.4 for BD and LF, respectively). Despite having the lowest C/N ratio, BD did not show the highest MFE, most likely related to a high slurry pH (8.0 compared to 7.1 and 7.0 for CS and LF, respectively), and hence larger ammonia losses. The MFE for acidified slurries were 80%, 50% and 66% of applied TAN for BD, CS and LF respectively, corresponding to an increase compared to non-acidified slurries by 59%, 58% and 21%. On both soil types, the trailing shoes did not manage to create soil slots with enough volume to contain the total volume of slurry applied. Spreading out of slurry beside the soil slots resulted in non-significant differences compared to trailing hose application in most cases, both in terms of ammonia emissions reduction and fertiliser effect. In conclusion, trailing shoes need softer soil for optimal performance, while slurry acidification effectively reduces ammonia emissions and increases the fertiliser value of slurries. Solid-liquid separation of cattle slurry is an interesting option, with an increase in MFE comparable to slurry acidification, but with the advantages of easier and safer handling and permitted according to EU regulations for organic farming.

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Potential leaching of N in a sandy soil amended with pH modified animal slurry

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A bio-based alternative to the conventional mineral fertilisers is livestock manure, an organic nutrient-rich material that is abundant in several EU countries. However, surface application of raw animal slurry to fertilize horticultural crops may be a source of foodborne pathogens and eventually contaminate the edible parts of the crops. On top of that, inappropriate slurry management can result in excess N losses as ammonia emissions (NH_3) or N leaching to underground waterbodies. Slurry acidification is a solution to minimize NH_3 emissions and alter slurry physico-chemical properties. On the other hand, slurry alkalinization has proved to be efficient to obtain a hyginized material. Chemical additives have been used in previous research studies to modify animal slurry pH. The possibility to utilize by-products from various industrial activities as slurry additives for pH modification is an option to reduce treatment costs. Our research aimed to assess the potential leaching of nutrients and pathogens (fecal coliforms) in a sandy soil amended with pH modified pig slurry. Three treatment strategies were considered namely acidification of pig slurry to pH 5 with sulphuric acid (H_2SO_4) and spent acid, bio-acidification to pH 5 with sucrose and a combination of H_2SO_4/sucrose and ultimately alkalinization to pH 9,5 with potassium hydroxide (KOH). Four leaching events were performed under laboratory conditions following the methodology used by Fangueiro et al. (2014). Considering the total amount of NH_4^+-N leached, the highest losses observed in acidified slurry with H_2SO_4 and spent acid (approx. 38% NH_4^+ leached/TN applied) while the H_2SO_4/sucrose treatment exhibited the lowest NH_4^+-N leached. The amounts of total NO_3^- leached were below 10% of TN applied in all treatments except untreated slurry that exhibited during the 3rd and 4th leaching events a considerable increase in NO_3^- leaching. Fecal coliform numbers followed a decreasing trend in all treatments during the experiment. The results obtained suggested that surface application of acidified slurry increased the risk of potential NH_4^+-N leaching, however, reduced NO_3^- leaching relative the control. Future studies should involve leaching experiments with different soil types as well as test nutrient leaching at field scale.

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Promoting animal slurry application in conservation agriculture

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The main objective of this project was to find viable solutions to promote the use of animal slurry application as an option to replace synthetic fertilizer in conservation agriculture (CA), a cropping system in which the soil disturbance and the uncovered soil surface must be avoided. For this, several experiments were performed to evaluate some strategies of slurry application on crop residues able to obviate the incorporation into the soil. Additionally, the joint application of slurry and urea was also assessed in order to reduce costs and time spent with transport and application of slurry. Finally, the timing of slurry application (before sowing or after plants' emergence) was also considered. The application of acidified slurry (AS) and the slurry placement under the stubble (US) efficiently reduced NH_3 emissions and led to crop yield and N_2O emissions similarly to raw slurry injection and ammonium sulfate applied on the stubble. The joint application of raw slurry and urea led to a large increase in NH_3 emissions but this problem was solved when urea (U) was applied jointly with AS (Silva et al., 2022a). Furthermore, AS + U performed similarly to U and AS, applied separately, regarding crop yield, nitrogen (N) recovery and N_2O emissions. Lastly, AS and AS + U applied eight days after oat sowing (T8) did not affect oat yield, N recovery, NH_3 or N_2O emissions in comparison to application on the sowing day (T0). However, NH_3 emissions from U were halved at T8. In conclusion, AS, US and AS + U are alternatives able to obviate slurry incorporation into the soil, helping to promote the replacement of synthetic fertilization in CA (Silva et al., 2022b). Moreover, AS + U treatment, by decreasing slurry application rates, improves the efficiency of slurry transport and land application, ensuring that farmlands located far from animal husbandry can have access to slurry as a nutrients source while helping to decrease N hotspots close to farms due to continuous slurry applications.

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Does digestion of manure and organic waste improve crop nitrogen recovery and reduce nitrate leaching and greenhouse gas emissions in organic farming?

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Anaerobic digestion of manure and organic waste generates renewable energy and contributes to close nutrient cycles. It is also suggested as an option to improve nitrogen (N) recovery in organic cropping, but possible tradeoffs like increased ammonia (NH_3) losses, nitrous oxide (N_2O) emissions or nitrate (NO_3) leaching are not well understood. Biochar amendments to digestate has been advocated to decrease N losses. The aim of this study was to understand the benefits and tradeoffs of digestion of manure and organic waste as well as biochar amendments to digestate compared to undigested liquid manure under organic cropping.

We set up a comprehensive field study in Switzerland with digestates from liquid manure with and without biochar amendments and a liquid digestate from an organic waste digestion plant and compared it to undigested liquid manure, mineral fertilization and a zero N control. We assessed yields, N use efficiency (NUE), NH_3 losses and N_2O emissions and mirrored the experiment in the Agroscope-Zurich lysimeter facility to evaluate NO_3 leaching. The ammonium (NH_4) N fraction of fertilizers was ^{15}N traced and allowed to study the initial NH_4-N flows over three crops (silage maize – winter wheat – winter barley). N application rates were based on total N content (120 - 140 kg N ha^{-1}).

Crop yields differed only slightly in maize and wheat. However, in barley digestates produced comparable yields to the mineral fertilization, but undigested liquid manure was significantly lower. Apparent NUE of manure-based digestates tended to be greater than for undigested liquid manure. A decrease rather than an increase in apparent NUE was observed when digestate was amended with biochar at 2 t ha^{-1} yr^{-1}. Crop NH_4-N recovery in the year of application was only 36 % for mineral and 16% for organic fertilizers in maize due to the very dry summer 2018, but in wheat in 2019 75% of NH_4-N was recovered from mineral fertilizer, 52% to 62% from digestate, but only 40% from undigested liquid manure. Low NH_4-N recovery could be explained by partly high NH_3 losses after application, which were significantly higher in digestates, 42% - 58% of applied, compared to undigested liquid manure with 29%. Emissions of N_2O tended to be increased by application of liquid organic compared to mineral fertilizers, but were mainly driven by soil temperature, soil moisture and soil mineral N. NO_3 leaching was low and did not exceed 25 kg NO_3-N $ha^{-1}yr^{-1}$. Overall digestion could be a measure to reduce N limitations in organic cropping with small environmental tradeoffs if NH_3 losses after application can be reduced. Biochar additions had no beneficial effect on N losses.

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The impact of slurry acidification on ammonia loss, greenhouse gas emissions and crop nitrogen supply

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Agriculture is responsible for c.85% of UK ammonia (NH_3) emissions with livestock slurry accounting for c.35% of losses. The UK has targets to reduce NH_3 emissions by 16% of 2005 levels by 2030. Acidification has been identified as a potential measure to abate NH_3 by altering the equilibrium between NH_3 (gaseous phase) and slurry ammonium (aqueous phase). Following application to land, the reduced NH_3 loss has the potential to increase the nitrogen (N) fertiliser replacement value of slurry. However, the conserved N may also risk increasing emissions of the greenhouse gas (GHG), nitrous oxide (N_2O). The UK is committed to achieve net zero emissions by 2050, therefore it is important that measures implemented to reduce NH_3 emissions do not result in increased GHG losses.

Field experiments were carried out at two arable sites: site 1, central England, sandy loam soil; site 2, eastern England, clay soil. Following separate autumn (2019) and spring (2020) slurry applications, GHGs and NH_3 (site 1 only) were measured using the static chamber (3 chambers/plot; 5 replicate plots) and wind tunnel techniques, respectively. Pig slurry and acidified pig slurry was applied using the ADAS plot applicator via trailing hose and surface broadcast methods. A control treatment was included where no N was applied. Grain yield and total N crop offtake were measured at harvest in 2020.

At site 1, acidification reduced NH_3 emissions by c.60-75%, from both slurry application timings. However, there was no effect ($P>0.05$) of acidification on N_2O emissions from the autumn application timing, and acidification reduced ($P<0.05$) cumulative N_2O emissions following the spring application. At site 2, there was also no effect of slurry acidification on total N_2O loss ($P>0.05$). At both sites on the day of application, acidification reduced ($P<0.01$) methane emissions, which was most likely caused by methanogen inhibition.

There was some evidence at both sites, that crop yields and grain N offtakes from spring application timings were greater ($P<0.05$) from acidified than from the unacidified slurry, reflecting reductions in NH_3 emission.

This UK study shows that slurry acidification was effective at reducing NH_3 emissions at land spreading leading to increased nitrogen recovery without 'pollution swapping' via increased GHG emissions.

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Regulation of N_2O emissions in two soils with surface-application of cattle slurry

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Manure is a key source of nitrogen for crops, but also a driver of N2O emissions from soil. As an intermediate of denitrification, N2O emissions from manure are regulated by oxygen consumption associated with manure C and N turnover and by gas exchange. A sandy loam soil had shown higher N2O emissions than a clay loam when both soils were incubated at the same bulk density and water content (55% water-filled pore space, WFPS) and amended with cattle slurry. This difference could either be due to a difference in O2 supply, or a higher degree of N2O reduction to N2, in the clay loam, or a change in N2O producing pathways. This was investigated in an incubation experiment where cattle slurry was again applied to the two soils. Repacked and pre-incubated soil cores with surface-applied cattle slurry at 100 kg NH4+-N ha-1 were incubated at 18-20°C in flow-through chambers flushed with atmospheric air. N2O, NO and CO2 concentration in chambers were continuously measured, and additional gas samples were taken manually for analysis of isotopic composition of soil-emitted N2O to evaluate N2O production pathways as well as the N2O reduction to N2. On day 13, when N2O emission rates were declining, chambers were flushed with pure helium to investigate the residual denitrification potential. Separate samples were destructively sampled on days 1, 4, 8, 13 and 22 for analyses of NO2-, NO3-, NH4+ and water-extractable organic C. The isotopic signatures of N2O (δ15Nbulk, δ15NSP and δ18O) were measured by isotope-ratio mass spectrometry (IRMS) on day 1,4 and 8. Data analyses are ongoing. From the N2O and N2 emission estimates obtained, sources of N2O and environmental controls will be discussed.

N-Print Plus: A multi-country, multi-language N footprint tool for consumers

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The N-Print project was launched in 2011 with a goal of creating nitrogen footprint tools for consumers to understand how their use of resources contributes to nitrogen pollution. The first tool, N-Calculator, was published in 2012 and focused on the US and The Netherlands (Leach et al., 2012). Since then, N-footprint tools using N-Calculator have also been developed for Germany, United Kingdom, Austria, Japan, Australia, China, Denmark, Tanzania, and Taiwan (e.g., Galloway et al., 2014).

This paper reports on the development of nitrogen footprint tools for Brazil, Denmark, Portugal, and the Ukraine using *N-Print Plus,* a new multi-country and multi-language tool. The project is part of INMS and since the project's beginning in January 2020, there have been multiple virtual workshops to develop the tool. We are pleased to report that the *N-Print Plus* tool is now operational and will be formally presented at the XXI International Nitrogen Workshop in Madrid, together with opportunities to get involved in the project.

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Personal consumption pattern matters: Nitrogen footprint in Ukraine

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Personal consumption pattern directly influences on waste generation and overall Nitrogen (N) footprint, an environmental indicator demonstrating the contribution of individuals to N pollution. Two main aspects can be distinguished: (i) unrelated to personal choice, such as sewage water collection and treatment efficacy provided by governmental authorities, and (ii) laid under personal responsibilities for individual demands, such as amount and types of consumed products, energy, transport and services use.

We quantified the mean N footprint in Ukraine was 21.9 kg N cap^{-1} for 2017. This was *ca.* 17% lower than reported for Germany, Netherlands and UK and *ca.* 50% less than those for the US and Australia. The food component contributed to 80% of the total personal N footprint in Ukraine through direct losses derived from food protein consumption, including those wasted upon food distribution, serving and wasted unconsumed, and after the partial N removal via wastewater treatment facilities. The largest portion of N wastes was associated with food production chain made 15.1 kg N cap^{-1} yr^{-1} with the majority (82%) generated from food animal system. Animal products consumed by Ukrainians generated 4-fold higher N wastes per 1 kg N of consumed animal food compared to plant products, where 1 kg N consumed led to 1.5 kg N losses to the environment. On average, individuals consumed 7% less animal proteins than plant-based ones in 2017. However, at improving socio-economic environment in Ukraine, the animal products consumption is expected to increase as it was shown for Romania (a member of the EU since 2007). Energy component made 8.5% (1.83 kg N cap^{-1} yr^{-1}) and embraced electricity and fuel consumption for household needs and transport use.

Although the overall protein consumption likely tends to increase in Ukraine following the individual income raise and stabilization of economics, the personal choice for a diet will then be formed by available information on healthy food and sustainable food production systems, which is a great opportunity window to introduce win-win options of how slightly changing one's diet to make oneself healthier simultaneously mitigating N pollution to the environment. This study was performed before the aggression of the russian federation and we believe that dissemination of these aspects will be of benefit upon post-war renovation and sustainable development of Ukraine.

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Regionalization of the Nitrogen Footprint for Brazil

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Reactive nitrogen (Nr) is necessary for food production, but it is also a by-product of energy consumption, and its losses can cause a cascade of environmental problems that negatively affect the environment and human health. The Nitrogen Footprint Calculator (N-Calculator) developed by Leach et al. (2012) allows the identification of imbalances in the nitrogen cycle in agro-food systems and their interface with society, promoting a base for discussion and education on dietary choices. The N-Calculator estimates Nr lost in units of resources consumed per capita by analyzing Nr emissions (or loss factors) in two sectors and their components: Energy (domestic; transport; goods and services) and Food (food production and consumption). In this work we present the N-footprint for Brazil through a greater detail for regional differences in the patterns of production and consumption within the country (North, Northeast, Central West, Southeast and South). The virtual nitrogen factors (VNF) were calculated for the production and residues associated with products of plant and animal origin, including forage and pasture used for animal feed. Animal products and crops analyzed correspond to foods selected based on their greater representation in the regular diet of the Brazilian population (pork, poultry, beef, milk, eggs, fish, oranges, bananas, lettuce, tomato, onion, potato, cassava, corn, wheat, rice, sugarcane, and beans). Foods were divided into large groups: Fruits, Vegetables, Cereals, Legumes, Meat and Animal By-products. National level consumption data from the Food and Agriculture Organization of the United Nations were used through the FAOSTAT platform, and regional productivity data from the National Institute for Geography and Statistics (IBGE), besides local references of nitrogen application for each crop in each region, including industrial and organic fertilizers, and content of absorbed, lost and exported N in agricultural and pasture/forage crops presented in regional literature. At the national scale, we found that beef production has the highest VNF of 10.9 g N loss/g N consumed, ranging from 4.86 to 16.93, followed by milk production (7.03, ranging from 4.49 to 9.58). Fruits presented an average VNF of 2.6 (1.4-4.4); vegetables of 1.5 (1.3 to 2.4); and grains 0.73 (0.6-1.2). The highest VNF of animal products was found in the North (corresponding to the Amazonia biome), while the lowest ones were in the South and Southeast. Regarding vegetables, VNF was highest in the Southeast and lowest in the Center-West. The Northeast presented the highest fruit VNF and the Southeast the lowest. The results show differences when comparing the five great regions in Brazil, in special when comparing regions that produce commodities and the ones that are producers of food for local consumption. The results show that N losses differ when comparing regions with different farm practices and the ones that produce commodities from the ones producing food for local consumption, which should be considered in policy discussions involving nitrogen and its role in meeting the objectives of sustainability and of food and nutrition sovereignty and security.

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A local and participatory perspective on restoring nutrient circularity in nutrient-saturated agro-food-waste systems

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Local nutrient cycles became disrupted through the introduction of fossil-based fertilizers and the resulted specialization and intensification of crop production and animal husbandry with strong spatial separation. The demand in feed beyond local supply due to the increased meat consumption over the last century, moreover disrupts nutrient cycles. Areas with specialization in livestock husbandry experience local nutrient surplus as a result of nutrient import as feed, while export of nutrients in the animal-sourced products is substantially lower. Thus, due to excessive manure availability, nutrient application is often in excess of crop demand, ultimately leading to nutrient losses for agriculture and harmful emissions to the environment. The stakeholders are in a lock-in within the current agro-food-waste system, which is still driven largely by economics. In order to counteract these prevailing issues, the nutrient balance needs to be restored through systemic change. Systemic change requires the cooperation of stakeholders stemming from the system. A regional implementation strategy, involving stakeholders, can specifically aid a transition towards circularity. District Cleves in the German state North Rhine-Westphalia is a region with intensive animal husbandry. A nutrient flow analysis of nitrogen, phosphorus, potassium and carbon flows simultaneously, utilizing localized data of the study area, confirmed that the district has a typical nutrient surplus. The import of feed, for livestock, implying an imbalance between locally available feed and kept livestock, is the biggest driver of the linearity of flows. This study aims to Identify and utilize stakeholders´ perspectives on a circular system by incorporating them into a agro-food-waste model in order to evaluated how nutrient flows in the system would be affected. To construct a circular nutrient scenario, input from stakeholders was acquired through questionnaires and interviews. A partial least squares analysis was employed to identify which points in the system affect aspects of circularity. The construction of a scenario utilized the range of answers of the different stakeholders acquired, such as about how livestock numbers would adjust to the reduction in available feed. The different stakeholders´ perspectives of a circular system were in this way reflected in the modelled range of performances of the system expressed through multiple indicators capturing aspects of circularity.

Importing feed or food? The impacts of shifting trade portfolio between US and China

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Current agriculture trade between the U.S. and China is dominated by feed crops. For example, the U.S. accounted for 88%, 38%, and 26% of China's sorghum, maize, and soybean imports in 2020, respectively. Instead of importing feed, directly importing animal products from the U.S. to China could potentially mitigate the existing excessive N loss from livestock production in China and encourage the coupling of crop-livestock production in the U.S. However, few studies so far have quantitatively assessed the impacts and feasibility of this option. Therefore, we designed three scenarios to evaluate the potential impacts of shifting from feed crops to animal product export from the U.S. to China to meet the increasing China's animal product demand: 1) producing more animal products in China instead of importing; 2) importing the required animal products from the U.S.; 3) importing feed from the U.S. and producing the animal products in China. Our preliminary results show that importing required animal products from the U.S. to China requires lower trade expenditure and lowers environmental damage costs (N surplus: 2.5 Tg N) for China. However, importing feed crops from the U.S. and producing the required animal products in China generates higher trade revenue and lower environmental damage costs for the U.S.
We also assessed the potential impacts on N surplus and N use efficiency (NUE) at the county scale in the U.S. by assuming that the expansion of each county's animal production and feed production is proportional to the national total. We found that most counties show lower coupled crop-livestock NUE and higher N surplus in the exporting animal product scenario. Specifically, counties in the Midwest corn belt region and in eastern North Carolina that support the most increased pork production show higher total N surplus (10-20 Gg N at the county-level) in the exporting animal product scenario. We will work with stakeholders to identify strategies to avoid such a decoupling of crop-livestock production on the county scale, especially in these potential hotspot counties. Overall, this study provides insights into the opportunities and challenges facing U.S. and China when shifting from predominantly feed crop trade to predominantly animal product trade between the two countries.

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Reactive nitrogen compounds and human health

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Human production of reactive nitrogen (Nr) via Haber-Bosch process and cultivation-induced biological N_2 fixation (BNF) has doubled global nitrogen (N) cycling over the last century. The most important beneficial effect of Nr is augmenting global food supplies due to increased crop yields. However, increased circulation of Nr in the environment is responsible for serious human health effects such as methemoglobinemia ("blue baby syndrome") and eutrophication of coastal and inland waters. Furthermore, ammonia (NH_3) emission mainly from farming and animal husbandary impacts not only human health causing chronic lung disease, inflammation of human airways and irritation of eyes, sinuses and skin but is also involved in the formation of secondary particulate matter (PM) that plays a critical role in environment and human health. Nr also affects human health via global warming, depletion of stratospheric ozone layer resulting in greater intensity of ultra violet B rays (UVB) on the Earth's surface, and creation of ground-level ozone (through reaction of NO_2 with O_2). The consequential indirect human health effects of Nr include the spread of vector-borne pathogens, increased incidence of skin cancer, development of cataracts, and serious respiratory diseases, besides land degradation. Evidently, the strategies to reduce Nr and mitigate adverse environmental and human health impacts include plugging pathways of N transport and loss through runoff, leaching and emissions of NH_3, nitrogen oxides (NO_x), and other N compounds; improving fertilizer N use efficiency; reducing regional disparity in access to N fertilizers; enhancing BNF to decrease dependence on chemical fertilizers; replacing animal-based proteins with plant-based proteins; adopting improved methods of livestock raising and manure management; reducing air pollution and secondary PM formation; and subjecting industrial and vehicular NO_x emission to pollution control laws. Strategic implementation of all these presents a major challenge across the fields of agriculture, ecology and public health. Recent observations on the reduction of air pollution in the COVID-19 lockdown period in several world regions provide an insight into the achievability of long-term air quality improvement. The focus of this presentation is on complex relationships between Nr and human health, highlighting beneficial and detrimental effects.

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MilKey: decision support system for sustainable GHG and N optimised milk production in key European areas

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Dairy production systems (DPS) are an essential part of European agriculture. Nevertheless, these systems face many challenges across the three pillars (3P) of sustainability (environment, economy, society). Therefore, it is essential that holistic concepts are developed to ensure sustainability of the sector, and to assist farmers and stakeholders in making knowledge-based decisions. The MilKey project aims to develop flexible concepts for sustainable milk production in key European Areas, allowing to identify synergies and trade-offs of measures dealing with single sustainability parameters, and to suggest targeted solutions for the different DPS in Europe. For MilKey, monitoring emissions is presented as crucial step for the design and implementation of mitigation measures to enhance the environmental sustainability of the sector. To this end, an online tool for monitoring indoor barn climate, animal stress and emission levels of air pollutants (OTICE) has been developed. The OTICE gives real time information on the temporal and spatial distribution of indoor air quality parameters, the level of animal activity and the emission levels of air pollutants such as ammonia (NH_3). Furthermore. MilKey develops and tests integrated sustainability assessment approaches that include GHG and NH_3 emission mitigation options for key DPS across Europe. As the main output of the project, the MilKey platform will provide relevant, accessible, and science-based information to stakeholders regarding emission mitigation and sustainability improvement. In this way, MilKey will assist stakeholders when making knowledge-based decision towards the design of more sustainable DPS.

MELS: Mitigation of greenhouse gas and nitrogen emissions from livestock systems

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National and international climate legislation requires significant reductions in GHG and N emissions in the short and long term. Livestock systems and manure management are major sources of GHG and N emissions. The reduction of GHG emissions will demand the implementation of existing and new mitigation technologies, and the documentation of their implementation in national emission inventories via activity data and emission factors. MELS gathers knowledge about the currently available mitigation measures in a global database, creates functional relationships between emissions and activity variables and develops methods to implement and document their use at the farm and national scales. MELS results are integrated into farm-scale Decision Support Systems and suggestions are being made on how to improve national emission inventory methodologies for livestock production systems.

The farm-scale DSS will be an open-source software specifically designed for countries lacking such a tool, based on the review of already existing tools and the assessment of future needs of the agricultural sector. MELS interacts with policy makers and inventory compilers, transferring project results to achieve higher accuracy and reportability of emissions in National Inventory Reports. By this, MELS reduces the costs of collecting activity data and investigates how transparency can be retained in the more complex emission inventories that MELS foresees for the future.

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ALFAMI: Model-based calculation of ammonia loss from field-applied manure for emissions inventories

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Ammonia (NH_3) volatilization from field-applied animal slurry (liquid manure) is a massive source of nitrogen (N) pollution globally. Many countries need to quantify the magnitude of emissions and effects of mitigation measures in order to meet reduction commitments. Although default Tier 1 emission factors (EFs) or national measurements are still common bases for inventory calculations, model-based approaches are gaining traction. In this contribution, we describe one such approach. The ALFAM2 model will form the calculation core of a new method and software package for inventory calculations developed as part of the ALFAMI project. The model is a low-order representation of the soil-manure system, with simple mechanistic relationships meant to capture essential physical and chemical interactions (Hafner et al., 2019). Model parameter values are determined from field measurements. The current parameter set is based on a subset of data from the ALFAM2 database (available through www.alfam.dk), with measurements from about 650 field plots in 6 countries. Effects are included for application method, weather, and slurry characteristics in the current parameter set. Mitigation practices—including incorporation, acidification, and separation—are reflected through changes in slurry placement, dry matter, and pH. Current efforts in the ALFAMI inventory tool project are focused on: 1) expansion of the ALFAM2 ammonia emission database with measurements from underrepresented regions or those that strengthen our understanding of mitigation measures, and 2) evaluation of the model and development of an improved parameter set. Development of the new software package will take place in 2023. The present contribution will summarize the project and model, discuss the advantages and disadvantages of a model-based approach, and present an evaluation of mitigation measures.

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Effect of N inputs by grazing cattle and fertilizer applications on pasture N_2O emissions

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Fertilized and grazed pastures are considerable sources of the greenhouse gas N_2O. While fertilizer applications usually lead to short emission pulses, animal excreta produce small-scaled emission hotspots resulting in a non-homogeneous source distribution. The strong spatial and temporal source variability represents an inherent problem for the quantification of gaseous emissions from pastures with chamber techniques. The eddy covariance (EC) method, integrating emissions over a larger footprint domain, are well suited to quantify total field-scale N_2O emissions, but the partitioning of emissions for different nitrogen (N) sources and the determination of field-scale grazing excreta inputs for emission factor calculation are still a challenge.

In our study on Swiss pastures, we combined eddy covariance and chamber measurements to investigate N_2O emission fluxes and emission factors on the patch and on the field scale. The investigated pastures were grazed by dairy cows in an intensive rotational management. They were additionally fertilized with organic and/or mineral fertilizer. The field-scale N_2O fluxes were quantified continuously with the EC technique using a fast response quantum cascade laser spectrometer for N_2O concentration measurements. Using the same analyzer, chamber measurements on real and artificial excreta patches were performed periodically with the manual fast-box technique (Voglmeier et al. 2019).

The pasture management and environmental conditions resulted in high temporal and spatial variations of the N_2O fluxes with highest values occurring after fertilization events and urine patch applications in the summer months under moderately wet soil conditions. Combining the EC and chamber measurements, a partitioning of the total annual N_2O emissions into urine/dung related emissions, fertilizer related emissions, and background emissions was performed. Consequently, grazing-related and fertilizer-related emission factors could be derived. They were found considerably lower for organic than for mineral fertilizer applications. The results for the grazing-related emission factor tend to be higher than the new IPCC global default EF_{3PRP} value of 0.4% for cattle (IPCC 2019).

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Impacts of land use change on nitrogen and carbon stocks in volcanic soils in Chile

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Quantifying the outcomes of land use change (LUC) for soil health or degradation and incentivizing sustainable land use is critical in Chile (Salazar et al. 2022). Central-southern Chile is influenced by the southern volcanic zones of the Andes and dominated by soils derived from volcanic ashes, mainly Andisols, where about 70% of agricultural activities in Chile are carried out (Casanova et al., 2013). In this zone, increased demand for agriculture commodities like meat and dairy incentivizes conversion of native forests to pastures and forage crops. This study aims to evaluate the impacts of LUC on nitrogen (N) and carbon (C) stocks in volcanic soils in Chile. We sampled soils at 24 farms in central-southern Chile spanning 800 km from 36° S to 43° S, where conversion of native forest to dairy or beef cattle pasture or forage crops had occurred. In each farm a <0.5 km transect with the same soil type was identified, where two or more of the following land uses were identified: native forest (NF); grazed native forest (GNF); pasture (P); and forage crop (FC). Composite soil samples of 3 samples per site-land use combination were collected by auger (0-30 cm) and bulk density (Db) was determined by the core method. Soil total C and N concentrations were determined on oven-dry soil samples by dry combustion. The N and C stocks (kg ha^{-1}) to 30 cm soil depth were calculated from concentrations and Db. Total N and C concentrations were highest under NF land use with values ranging between 0.7-1.5% and 11-18%, respectively, whereas the lowest values were in P and FC land uses with values ranging between 0.6-1.2% and 7-15%, respectively. Conversion of NF to GNF and P land uses increased Db from 0.3 to 0.5 and 0.6 Mg m^{-3}, respectively. Along the land use gradient described above from NF to FC, the change in soil N and C stocks ranged from negligible to a 40% loss. Volcanic soils have a low Db (< 0.9 Mg m^{-3}), but land uses that involve grazing generated soil compaction that outweighed losses in total N and C concentrations under these land uses when calculating stocks. We conclude that LUC from NF reduced soil total N and C concentrations and in some cases soil aeration. Sustainable soil management such as minimum tillage and grazing management such as lower stocking rates or rotational grazing to increase N and C recycling and maintain soil quality should be prioritized.

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Multi-trophic interactions between microbivorous and herbivorous mesofauna: implications for N cycling and plant growth

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In comparison to soil bacteria, archaea and fungi, the soil micro- and mesofauna (protists, nematodes) are very much understudied. Soil nematodes are composed of multiple feeding groups that can strongly determine plant growth and plant-plant interactions (Wang et al., 2019). Different trophic groups of nematodes control distinct energy channels, though their exact trophic links remain little understood and most individual studies focused on bacterivorous nematodes, largely neglecting herbivorous and fungivorous nematodes (Zhao and Neher, 2014). To the best of our knowledge no research has been done on how the multi-trophic interactions among these three feeding-groups of nematodes and microbial community impact nutrient mineralization and plant growth. A mesocosm experiment was conducted to investigate how herbivorous and microbivorous microfauna, separately and in combination, enhance N mineralization and plant growth. Loamy sand soil was selectively sterilized by gamma irradiation (6 kGy) and pre-incubated for one month to recover the activity of the indigenous micro-flora community caused due to the irradiation effect. *Pratylenchus zeae*, *Aphelenchus avena*, and *Rhabditis oxycera,* representing herbivorous, fungivorous, and bacterivorous nematodes, respectively, were inoculated in these soils alone and in all combinations, and rye-grass was used as a model plant and incubated in custom made microcosms. After two months, plants were harvested and analyzed, and the soil was analyzed to evaluate the impact of trophic interaction on plant growth. There was no significant change in N% of shoot and root within all the treatments and mineral N (NH_4^+ + NO_3^- concentration) was low for all treatments. Nonetheless, plant biomass (shoot and root) was significantly higher by 11.4 and 45.2% in the treatment with all three trophic groups of nematodes combined compared to the presence of microbes only (control treatment). The change in root architecture due to the presence multi-trophic nematodes further indicated that the root growth was benefited from different feeding group of nematodes.

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Improvement and refinement of the UK inventory of nitrous oxide emissions from agriculture.

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The submission of annual national greenhouse gas (GHG) inventories is a requirement under the United Nations Framework Convention on Climate Change (UNFCCC) for Parties included in Annex I to the Convention. Agriculture is one of 5 sectors that must account for their emissions, and in the UK, it comprises ca. 9% of the total emissions (2019). IPCC Tier 1 approaches are applied by countries to calculate emissions when this annual reporting commences and in the case of the UK, up until 2015 this default methodology was mostly applied which resulted in emissions of N_2O/CH_4 contributing to total emissions in a ratio 60/40. Uncertainties in emissions were approx. +/- 130% and +/- 11% for N_2O and CH_4 respectively. Between 2010-2015, the UK Government and the Governments of the constituent countries of the UK (Scotland, Wales, N Ireland), funded three projects aiming to develop a new improved GHG inventory for agriculture that would better reflect the UK's nitrogen management, soils and climates (for N_2O), livestock breeds, diets (for CH_4) and management practices (activity data), to result in more accurate and less uncertain accounting of emissions. These three projects aimed (amongst other activities) to: i) improve soil N_2O emissions, developing protocols, providing training and national capacity, and included 37 field trials on different soil/climate conditions for different N fertilizer and manure applications, as well as excreta deposited by grazing livestock; ii) improve CH_4 emissions estimates from enteric fermentation and manure management for dairy, beef and sheep; iii) synthesize the data, resulting in country specific (CS) emission factors (EFs). The newly generated data have been gradually incorporated in the inventory since the 2016 inventory year, resulting in an improved CS inventory which changed the emissions contributions for N_2O/CH_4 to ratios: 36/60. Further changes include much lower EF for grazing and manure applications compared to the changes in EF for fertilizer. The improved UK inventory estimates emissions using a modelling tool at a 10 x 10 km spatial disaggregation, accounting for the influence of long-term average annual rainfall and application rate for fertilizer N N_2O EFs. The N emissions (N_2O, NH_3, NOx, N_2) are estimated using a N balance approach and the CH_4 emissions for major categories are estimated using typical diets. Overall, the emissions in the improved inventory are reduced compared to the original inventory as well as the uncertainties for N_2O and CH_4 which are approx. +/- 15% and +/- 4%, respectively.

Further, the improved UK inventory is being continuously revised, with planned changes to fully disaggregate emissions from the manure management continuum (housing, manure storage and land application).

Effects of different cover crops before maize cropping on soil nitrogen dynamics and N_2O emission

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Cover crops are recommended to reduce nitrate leaching and soil erosion. Their effects on nitrous oxide emission are less clear. The objectives of our field experiments were to determine the influence of three different winter cover crops (saia oat, spring vetch, winter rye, bare fallow as control) before cropping of silage maize in spring on soil mineral N dynamics and N_2O emission. We analysed cover crop effects in year-round replicated field plot experiments at two sites in northern Germany (Kiel and Uelzen) during two consecutive years. Mean above ground cover crop maximum N yields were 61 ± 19 kg N ha^{-1} for the N_2 fixing spring vetch, 50 ± 13 kg N ha^{-1} for the frost-resistant winter rye, and 50 ± 12 kg N ha^{-1} for the frost-sensitive saia oat. The amount of mineral N fixed in cover crop biomass reflects the potential to reduce over winter nitrate leaching and related indirect N_2O emission (in the case of the non N_2-fixing saia oat and winter rye) and it indicates the amount of N that is potentially transferred to the following main crop maize. We found no significant effect of cover crops on the total N_2O emission in the cover crop period (from cover crop seeding to maize seeding on average 0.7 kg N_2O-N ha^{-1} at the site Uelzen and 0.4 kg N_2O-N ha^{-1} at the site Kiel). N_2O emission during the maize period (from seeding to harvest of silage maize) was influenced by dry matter and nitrogen yield of incorporated cover crop biomass. Cover crops before maize increased N_2O emission from the maize field at the site Uelzen (only in the second year; bare fallow before maize: 0.8 kg N_2O-N and cover crops before maize 1.1 to 1.6 kg N_2O-N) but not at the site Kiel (mean emission of 0.8 kg N_2O-N during the maize period). Maize yield related direct annual N_2O emissions were not increased in systems with cover crops in Kiel, but there was a tendency of increased maize-yield-related N_2O emissions in both years in Uelzen: However, the effect was significant only in the first year.

All in all, our results show that cover crops reduce the risk of indirect N_2O emission induced by nitrate leaching but direct N_2O emission can be increased (depending on site). Effects of cover crops on soil organic carbon reproduction or synthetic nitrogen fertilizer savings can provide additional contributions to climate protection. Growing cover crops is probably not the most efficient way to reduce greenhouse gas emission of arable cropping systems but it a measure with many synergies in the fields of soil protection, groundwater protection and biodiversity.

Evaluation of N_2O fluxes using the eddy covariance technique: first observations on a barley field in central Germany

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Nitrogen-intensive agriculture is expected to increase to meet the food demands for human nutrition for the increasing world population. Management practices for improving crop production are challenged by the need to reduce nitrous oxide (N_2O) emissions, a potent and long-lived greenhouse gas. These N_2O emissions from crop fields exhibit large spatio-temporal variability due to soil heterogeneity, variability in management, and environmental events. The limitations of the commonly used static chamber technique to quantify N_2O fluxes have been well documented, especially regarding its limited spatial information and coarse temporal data, which contributes to the uncertainty of greenhouse gas inventories. The eddy covariance (EC) technique offers the opportunity of providing data at a high temporal resolution over larger surfaces than chambers. However, due to the only recent availability of the instrumentation and the large costs, studies monitoring N_2O fluxes in croplands using EC are very scarce.

This study aimed at quantifying the exchange of N_2O fluxes in a German crop rotation, evaluating the short-term variability of the fluxes, and investigating their drivers (i.e. management practices and environmental conditions). For this purpose, an EC-N_2O system consisting of a sonic anemometer and a fast response closed path N_2O analyzer (Los Gatos Research, San Jose, USA) was set up in March 2022 in a barley field in central Germany. Two fertilization events took place in April and May 2022, with a total of 85 Kg N ha^{-1} applied during the study period. Meteorological conditions (soil temperature and moisture, air temperature and humidity, radiation, rainfall, and wind) were also monitored.

Preliminary results confirm the large temporal variability in N_2O fluxes. A particularly strong, short-lived pulse was measured after fertilization under wet conditions in early April (water-filled pore space around 70%, fluxes up to 2.95 nmol m^{-2} s^{-1}). However, the response of N_2O emissions following the second fertilization event was much lower and fluxes were about 2 times smaller. This was possibly caused by the dry conditions in which this second fertilization event took place (water-filled pore space of 20%). Our study adds to the body of evidence that soil moisture is a critical parameter for N_2O hot moments and highlights the need for continuous monitoring of N_2O fluxes in agricultural systems. Data from March to September 2022, including the intercrop period, will be presented and we will estimate the N_2O emission factor for the study period.

Effect of drip (surface *versus* subsurface) fertigation and synthetic N sources on N uptake, N_2O emissions and related key N-cycling genes

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A two-year field experiment located at central Spain was set-up to test the effect of drip fertigation (surface and buried at 30 cm) and different N sources (unfertilized control, calcium nitrate, CN, ammonium sulphate, AS, and AS with the nitrification inhibitor DMPP, AS+DMPP) in a maize (*Zea mays* L.) crop. Nitrous oxide (N_2O) fluxes, the abundances of key genes involved in nitrification and denitrification, crop yield and N acquisition were measured. Cumulative N_2O emissions and related N_2O emission factors were lower than those from the IPCC and associated to irrigated maize, highlighting the effectiveness of drip-fertigation as a N_2O mitigation practice. Buried drip tended to decrease N_2O emissions, while AS was the N source leading to the highest cumulative fluxes in both campaigns. The AS+DMPP treatment was more effective during the second year, reducing N2O emissions by 66% (versus AS-only). During the first year, the abundances of key N-cycling genes were higher in unfertilized control than in fertilized subplots, although this was only observed during the fertigation period. During the second year, the effect of AS+DMPP was more evident, reducing the abundance of both nitrifying and denitrifying genes. No differences were observed in grain or biomass yields between drip irrigation systems. The AS+DMPP treatment increased grain yields (by 18%) and SPAD index at some sampling dates in comparison with AS-only, even though this was only observed in the second campaign. During the first year, surface drip significantly increased crop N recovery efficiency, showing the combination of subsurface drip and CN the lowest values. In the second year, buried drip performed better and resulted in the highest SPAD index values and a more precocious crop development. All tested treatments yielded promising environmental and agronomic performance, even though we should highlight the combination of subsurface drip fertigation and AS+DMPP applied through three fertigation events as the management practice with the highest potential to improve the balance between yield stability and N_2O emissions mitigation.

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Assessment of the effects of manure additives on gaseous emissions and grass yield in a North-Western Atlantic climate

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Landspreading of slurry is associated with the release of ammonia (NH_3) and greenhouse gas emissions which contributes to air pollution and global warming. Irish agriculture accounts for 99% and 37% of national NH_3 and greenhouse gas emissions respectively. Furthermore, Ireland is in breach of its NH_3 emissions ceiling set by the European Union National Emissions Ceilings Directive. To ensure compliance, Ireland must reduce NH_3 emissions by 1% relative to 2005 in 2020–2030 and by 5% afterwards. Slurry amendments have the potential to mitigate NH_3 emissions from slurry landspreading. However, there is limited information regarding the impact of these amendments on other N loss pathways and nutrient availability for plant utilization in Ireland. The goal of this study was to investigate the efficacy of chemical amendments on gaseous emissions (NH_3 and N_2O) and grass yield in a North-Western Atlantic climate. Experimental work was conducted on a permanent grassland site (moderately drained soil) at the Teagasc research centre in Johnstown Castle in Wexford, Ireland. The trial was established as a completely randomized block design with five blocks incorporating agronomy plots (4 m x 2 m) and microplots for NH_3 (three blocks) and nitrous oxide (N_2O) measurements (1.5 m x 1.5 m). Six treatments were evaluated as follows: control (no nitrogen treatment), untreated slurry, slurry + sulphuric acid, slurry + gypsum, slurry + biochar and Urea with urease inhibitor. Treatments were applied three times in the year (i.e., April, June and August) after grass harvest. Nitrogen treatments were applied at a rate of 120 kg N ha^{-1} $year^{-1}$ in three equal splits. NH_3 emissions were measured within the first week of application using the static chamber method with a photoacoustic gas analyser. N_2O emissions were measured using the static chamber technique during the growing seasons. Results indicate NH_3 reductions of 19%, 12% and 10% in acidified slurry in April, June and August applications respectively. The effect of the other slurry treatments on NH_3 varied by the season. Low NH_3 emissions during the measurement period may have confounded the expected effect of the amendments. N_2O emission factors were in the order; slurry + sulphuric acid (0.23%) > slurry + gypsum (0.17%) > untreated slurry (0.11%) > slurry + biochar (0.09%) > urea with urease inhibitor (0.04%). There were no significant differences between N treatments relative to grass yield. Results from the second year (i.e. spring application) of the trial show reduction in NH_3 in amended slurry treatments. Further analyses are underway to determine emissions and yield parameters for the rest of the year.

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Genetic diversity in nitrogen fertilizer responses and N gas emission in modern wheat

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Crops assimilate nitrogen (N) as ammonium via the glutamine synthetase/glutamate synthase (GS/GOGAT) pathway which is of central importance for N uptake and potentially represents a bottle neck for N fertiliser-use efficiency. The aim of this study was to assess whether genetic diversity for N-assimilation capacity exists in wheat and could be exploited for breeding. Wheat plants rapidly, within 6 h, responded to N application with an increase in GS activity. This was not accompanied by an increase in GS gene transcript abundance and a comparison of GS1 and GS2 protein models revealed a high degree of sequence conservation. N responsiveness amongst ten wheat varieties was assessed by measuring GS enzyme activity, leaf tissue ammonium, and by a leaf-disc assay as a proxy for apoplastic ammonia. Based on these data, a high-GS group showing an overall positive response to N could be distinguished from an inefficient, low-GS group. Subsequent gas emission measurements confirmed plant ammonia emission in response to N application and also revealed emission of N2O when N was provided as nitrate, which is in agreement with our current understanding that N2O is a by-product of nitrate reduction. Taken together, the data suggest that there is scope for improving N assimilation capacity in wheat and that further investigations into the regulation and role of GS-GOGAT in NH3 emission is justified. Likewise, emission of the climate gas N2O needs to be reduced, and future research should focus on assessing the nitrate reductase pathway in wheat and explore fertiliser management options

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High temporal frequency measurements of soil N_2O emissions in a wheat crop under irrigated Mediterranean conditions: impact of tillage and fertilizer type

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Nitrous oxide (N_2O) is an important greenhouse gas and agriculture is one of the sectors with largest contributions. Farming practices (i.e. tillage and fertilization) affect N_2O production drivers in the soil, so they have a direct influence in their emission to the atmosphere (Krauss et al. 2017). Therefore, a detailed understanding on the impact of different management practices is needed to develop effective mitigation strategies.

Compared to manual chambers, automated continuous systems increase the measurement frequency of soil N_2O emissions. Thus, among their advantages, they allow not to miss any emission peak (such as after an unexpected rainfall event), and then they enable to capture in a more precise way temporal dynamics of soil N_2O emissions (Grace et al. 2020). To date, the number of studies using automated continuous systems in Mediterranean regions are scarce. So, its implementation would contribute to increase the knowledge under these conditions.

The main objective of this study was to assess the impact of different tillage (i.e. conventional tillage and no-tillage) and fertilizer types (i.e. inorganic and organic fertilizer) on soil N_2O emissions in an irrigated wheat crop, located in the NE of Spain. High frequency gas measurements were performed during the wheat growing season and after harvest with a system consisting on automated chambers linked to an in-situ photoacoustic analyzer (Gasera Ltd.). In addition, manual gas measurements were taken every 10 days. The same day, soil inorganic N content was determined. Besides, soil moisture and temperature were monitored through the experiment to understand N_2O flux variations.

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Knowledge for integrated nutrient management: flows, targets and possible measures in the European Union

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In the EU Biodiversity Strategy to 2030, the Farm to Fork Strategy and the Zero Pollution Action Plan the European Union has set an ambitious and ground-breaking goal to reduce by 50% nutrient losses to the environment (air, water, soil) by 2030, while preserving soil fertility. To this end, the Commission will work with Member States to develop an Integrated Nutrient Management Action Plan (INMAP). The 'Knowledge for INMAP' project aimed to gather scientific knowledge and data available in the EU to support the discussion and preparation of the Integrated Nutrient Management Action Plan.
This contribution will present the results of the study. First, we quantified the current flows of nitrogen and phosphorus in the EU considering all sources and sectors involved (agriculture, industries, urban, energy and transport) and all environmental losses in air, water, and soils, and we looked at the spatial variability. Second, we evaluated the distance to environmental targets, considering the EU existing legislation and overarching strategies, and planetary boundaries. Finally, we explored the effects of measures to reduce nutrient pollution at various intervention points in the nutrient cycle, considering new scenario modelling assessments (based on several models, i.e. DayCent, EMEP, CAPRI, GREEN, GRAFS), and we analyzed the results in view of the ambitious nutrient reduction target.

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Mapping of waste water treatment technologies for suitable policy implications to control nitrogen pollution in Delhi, India

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Dumping of untreated or partially treated sewage is one of the biggest cause of rising nitrogen pollution, particularly ammonia in the water bodies of rapidly growing urban centres of India like Delhi evoking the need to enhance and improve the existing waste water treatment capacity / technologies and promote the re-use of treated waste water for non-potable uses after suitable treatment to reduce the nitrogen pollution.
Accordingly, in the present study, existing waste water treatment technologies of Delhi have been mapped to find out most appropriate technique to control nitrogen pollution from waste water. Results showed that out of 5 treatment technologies deployed, Moving Bed Biofilm Reactor (MBBR) technology has emerged as best available option to reduce nitrogen as NH_4 from waste water in Delhi. The quality of treated effluent of Akashardham STP deploying MBBR technology was found to be the best with NH_4 reduced by 93% i.e., from 26.93 mg/l in inlet to 1.94 mg/l in outlet from 2019 to 2022. However, only 1 STPs of Delhi (Akashardham) works on MBBR and this number needs to be enhanced in future for better nitrogen pollution control from the Sewage Treatment Plants of Delhi *via* suitable policy implications. Out of total 306 Indian policies collected under South Asian Nitrogen database, 58 policies were found to target the water as a sink under threat. Policies with large impact and high relevance for nitrogen pollution control like National Water Policy (2012) and National Policy on Reuse of Treated Water (2018) can be amended or new policies can be developed using the outputs of current study demanding the need of updating the conventional techniques like ASP or replacing them with new advanced techniques like MBBR for minimizing the nitrogen leakage into the environment *via* the untreated or partially treated waste water.

Exploring the potential of the Horizon Europe candidate partnership on Agroecology Living Labs and Research Infrastructures to reduce farming reactive nitrogen losses.

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According to recent IPCC and IPBES assessments, current food production system drives degradation of land productivity, water resources and soil health, as well as biodiversity loss at multiple spatial scales, ultimately compromising the sustainability of food production systems. The release of reactive nitrogen species from farming practices is one of the main contributors to most of those adverse impacts, which are experienced at multiple spatial scales.

Several European Union policy initiatives related to the European Green Deal such as Farm to Fork and the Biodiversity strategy 2030 set targets to reduce farming nutrient surpluses. Their fulfilment will require further research and innovation efforts. A comprehensive view will be needed to prevent pollution swapping and non-desirable social and economic side-effects. Agroecology spans the agricultural, environmental, and socio-economic domains and covers the full farm to fork range. Therefore, it is considered a suitable approach to provide the innovations that are needed to transform current farming systems into sustainable ones. Innovations uptake is an urgent matter due to the short time frame set to achieve the emission reduction objectives and agroecology Living Labs are considered relevant in this regard since they are, by definition, user-centered, connected to real-life settings and based on co-creation and multi-stakeholder involvement.

Long-term and coordinated funding of agroecology research is needed to avoid research fragmentation and knowledge losses. Hence the Standing Committee on Agricultural Research (SCAR) launched in 2021 a strategic working group on agroecology (SCAR-AE) to develop the concept and the scientific research and innovation agenda (SRIA) of a candidate European partnership titled “Accelerating farming system transition: agroecology living labs and research infrastructures” (AELLRI). This partnership shall last for seven to ten years and will be launched under the Horizon Europe 2023-2024 work program as a co-funding instrument between member states, associated countries, and the EC. The concept of AELLRI is now available[i] and its draft SRIA has been delivered for public and stakeholders’ review. The XXI N International workshop will be an excellent opportunity to better understand and identify research- and policy-driven needs and approaches aiming to incorporate them in AELLRI’s SRIA.

[i]https://ec.europa.eu/info/research-and-innovation/research-area/agriculture-forestry-and-rural-areas/ecological-approaches-and-organic-farming/partnership-agroecology_en

To what extent public policies have reduced nitrogen flows in Brittany, the leading agri-food region in France: Analysis of available public data

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Brittany is one of the French and European regions with a high nitrogen surplus for more than 30 years resulting in a high level of nitrates in rivers and the proliferation of green algae on the coast. Public policies, regulatory (nitrates directive, NEC directive, IED directive), or incentive have been put in place. These policies have enabled a broader deployment in Brittany of measures aimed at nitrogen input reduction (herd reduction, manure treatment, feeding strategies), farmers' information, and improvement of fertilization and manure storage/spreading techniques. More recently, new public policies relating to climate, energy, and agroecological transition have also affected the nitrogen flows via the mobilization of livestock manure as biomass (biogas production) by encouraging organic production. These various policies have undeniably contributed to the nitrogen reduction applied in Brittany and the nitrate levels in the waters. These went from 204.2 kg N/ha in 2000 to 178.8 kg N/ha in 2018 for the nitrogen applied and from 53.7 mg NO_3 /l in 2000 to 37.3 mg NO_3/l in 2018 for the average nitrate levels in Brittany waters. The nitrogen surplus (54.5 kg N/ha in 2000) was 26.6 kg N/ha in 2018, partly explaining the very thorny problem of the proliferation of green algae which persists in Brittany. Between 2011 and 2018, the regional pressure in total nitrogen (kg N/ha) is reduced by around 4% but with variable values between areas (stability or increase). On a regional scale, the pressure from manure nitrogen shows an average reduction of 11.2% in 2011/2018, but this masks again various situations between livestock and between areas. This fact can minimize specific sources of nitrogen that are more difficult to control (pasture, outdoor run). In addition, 2015/2018 data invalidates or confirms the 2011/2018 evolutions. A reduction in ammonia emissions between 2011 and 2018 is also observed due to the consequent decrease in ammonia emissions from pig herds, unlike cattle and poultry. These changes since 2011 will positively or negatively impact nitrate concentrations in surface waters depending on the nitrogen and hydrological legacies. These evolutions according to livestock and production area indicate that public policies should be more sectoral and spatial, which may seem contradictory with integrated or systemic approaches. Nevertheless, local and targeted measures can be complementary regarding applied nitrogen. The additional solution currently envisaged for some areas is the Payment for Environmental Services. This choice can be questioned regarding the choice of some farmers to move towards organic farming and the new CAP stopping financial support to organic agriculture.

Defining farm-specific sustainability nitrogen-use-criteria that ensure the compliance with regional environmental thresholds for the application in EU-policy frameworks

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Nitrogen (N) losses caused by agricultural production may have significant negative effects on the environment. Tackling them on EU-scale is only possible through a policy framework that a) can be consistently applied by different EU-member states, b) gives farmers the possibility to take individual management decisions, c) is sufficiently clear and transparent, d) easy to implement and e) effective in achieving regional as well as global environmental and climate targets.

The European Nitrogen Expert Panel (EUNEP 2016) has developed an easy-to-use indicator set based on farm N-input and N-output which provides farmers with the possibility to assess and policy makers with the possibility to control farm nitrogen management. But defining general and on EU-scale applicable indicator-limits, that ensure that environmental goals on different regional scales are achieved, is not possible. The reason for that is twofold. First, the effects of nitrogen on biodiversity, surface waters and groundwater differ regionally as 1) ecosystems have differing capacities in buffering pollution, 2) N-losses depend on geographical conditions such as soil, slope and climate, 3) denitrifaction rates depend on soil conditions and 4) prevalent N-pollution depends on regional N-Emissions from other sources. Second, for mineral fertilizer the maximal achievable Nitrogen use efficiency (NUE) is higher than for organic fertilizer, but its usage introduces additional and virgin N in the N-cycle and surpresses the usage of manure. We therefore propose a policy framework which integrates farm-specific nitrogen-use-criteria that take into account the different NUEs of different fertilizer types as well as the geographic farm location.

The necessary information for calculating the farm-specific criteria must be derived from different sources in order to ensure highest possible accuracy: information on N-in and -output from the farm; data on slope, soil and climate from regional authorities and environmental thresholds from EU-legislation or scientific literature. The algorithms needed to calculate the relevant regional critical surpluses which are the basis for the critera are derived from a modelling framework recently published by de Vries et al. (2021). In order for the facilities to assess their farm-specific criteria, all the aformentioned information must be implemented into a smartphone or computer-application. We propose here to further extend FaST (https://fastplatform.eu/about), a tool developed by the EU-COM which is originally designed for fertilizer planning, but already entails many necessary elements for assessing and monitoring the farm-specific nitrogen-use-criteria.

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From Urban Nitrogen Budgets to Sustainable Development Goals: N governance in Urban context

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Urban Nitrogen Budgets (UNBs) have been used to elucidate nitrogen's fate in urban environments, and better diagnose the relevance of the role cities are playing in anthropogenic activities (Winiwarter et al., 2020). The international community's growing commitments to halving nitrogen waste by 2030 concurrently exhibit the imperative need for effective policy strategies targeting the most significant sources of nitrogen pollution.

Here, we first present the methodological framework of UNBs applied to four test cities in Beijing, Shijiazhuang (China), Vienna (Austria), and Zielona Góra (Poland). Conceptually, a flow-and-pools methodology derived from EPNB's Guidelines for National Nitrogen Budgets structures the budgets into potential pathways and allows comparability between test areas. Following that methodology, the Material Flow Analysis freeware STAN (https://www.stan2web.net/), including an uncertainty treatment, is used as a common modeling framework to develop the respective UNBs.

Second, we build on indicators to draw linkages between the modeling outcomes and N governance across different scales. Following identifying dominant pathways of N pollution, we use various indicators, like N losses to water, N surplus, or NUE, to highlight primary policy needs at the urban/peri-urban scales and address potential options supporting the development of a circular economy. Further, we translate such local indicators into the Sustainable Development Goals (SDGs) framework, extending from a Sustainable Agriculture approach (Zhang et al., 2021). This mapping notably allows us to compute scores expressing the degree to which test areas reach the respective SDG targets. Our findings show clear difficulties of Chinese cities in achieving the specific targets of Nitrogen Use Efficiency (linked to SDG 1) and surface N losses (related to SDG 14), while both European and Chinese cities struggle with meeting the criteria for NH3 emissions from agriculture (related to SDG 3) and N surplus (linked to SDG 2). The approach provides, to a greater extent, a new insightful tool for urban N governance.

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Impacts of agricultural practices on large scale losses of ammonia, greenhouse gases, nitrate and phosphate to air and water

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To gain insight in the environmental impacts of crop, soil and nutrient management, an integrated model framework INITIATOR (Integrated Nutrient ImpacT Assessment Tool On a Regional scale) was developed predicting national totals and the spatial variation in: (i) emissions of ammonia and greenhouse gases from animal housing systems and agricultural soils and (ii) accumulation, leaching and runoff of carbon, nutrients (nitrogen, N, phosphorus, P, and base cations) and metals in or from agricultural soils to ground water and surface water in the Netherlands. Key processes in soil are included by relative simple empirical linear or non-linear algorithms to maintain transparency and to enable data availability for spatially explicit application. Calculated national trends in nutrient losses over 2000-2020 compared well with independent estimates and showed a reduction in N and P input of 20% and 30%, whereas the surplus declined by 20% for N and 80% for P due to slightly increased crop yields at reduced inputs. This was accompanied by a reduction in national atmospheric emissions of ammonia and nitrous oxide near 30-35%, N and P runoff near 20-25%, whereas the emission of methane increased with 7%.

We evaluated various mitigation measures reducing air emissions of ammonia and greenhouse gases and leaching and runoff of N and P in view of policy ambitions for climate, soil and environmental quality for 2050, i.e. a reduction of 50%, 42%. 20% and 40% in NH3 emissions, GHG emissions, N leaching/runoff and P runoff, respectively. The measures focused on a combination of animal feeding, low emission housing and application, improved nutrient management, improved soil management and improved crop management at 100% and 50% effectiveness/implementation, separate and combined with 50% livestock reduction. Our integrative analysis showed that full implementation of all relevant measures can reduce ammonia emissions by 46% and N runoff by 38%, but their potential is much less for reducing P runoff and greenhouse gas emissions, being 8 and 14%, respectively. The combination of the more likely 50% implementation of measures with 25% livestock reduction leads to a comparable reduction in ammonia emissions of 39%, in N runoff of 38% and in greenhouse gas emissions of 19%. However, the potential to reduce P runoff remains small, being near 7%, since it takes a very long period to mine the soil with P. The results show that required reductions from Dutch agriculture are not possible with improved management only, but also requires livestock reduction, while the climate ambitions are even then hard to fulfil.

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Quantifying nitrogen flows in European agricultural grasslands and fodder crops: overview and key challenges

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Grasslands and arable fodder crops (GAFs) play a central but poorly quantified role in European agriculture. GAFs cover more than 40% of Europe's agricultural area and likely supply somewhere between 30% and 50% of Europe's livestock feed protein. GAFs receive a large share of European synthetic and manure nitrogen inputs, and additionally, legume-containing GAFs biologically fix non-negligible amounts of nitrogen. Moreover, perennial GAFs attract growing interest due to their contributions to local feed self-sufficiency and multiple environmental benefits including higher biodiversity and increased stocks of soil organic matter compared to annual crops. However, accurate quantification of GAF productivity, nitrogen flows, and environmental performance is challenging due to their high diversity in combination with limited primary data collection on GAFs.

Here, we will present a quantitative overview of GAF nitrogen flows in European agricultural soil-crop-animal systems, considering GAFs as a source of livestock feed protein, as a user of synthetic and manure nitrogen inputs, and as a source of biologically fixed nitrogen. We will provide a historical overview of arable fodder crops (forage legumes, temporary grasslands, fodder roots, and green maize and other cereals harvested green) since 1961 in 26 European countries based on our previous work (Einarsson et al., 2021) and quantitatively compare the role of European arable fodder crops to that of permanent grasslands as quantified in various literature sources.

We discuss two approaches to improve quantification of GAFs. First, there is a clear need for new and improved primary data sources. We point out key data gaps and discuss possibilities to address these. Second, there is a major potential for more efficient use of existing data. In particular, we see a major potential in innovative data-fusion methods leveraging expert understanding to combine information from international and national databases. We present several examples of such approaches.

In summary, we here demonstrate the huge, diverse, and sometimes underestimated role of GAFs in the soil-plant-animal system of European agriculture, and point to recent and emerging approaches to reduce the considerable uncertainties that remain.

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A nitrogen flow model to assess crop residue management in integrated crop-livestock systems at a territorial scale in France

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In order to feed the growing world population there is a need to increase food production. The development of the Haber-Bosch process has made it possible to produce synthetic fertilizer in large quantities that help increase agricultural yields. However, the higher use of synthetic fertiliser has resulted in an increase in reactive nitrogen in the atmosphere, aquatic and terrestrial ecosystems, notably having impacts on air quality, human health, acidification, eutrophication and climate change (Erisman et al. 2013).

In France, a trend of specialisation in agriculture has led to the development of agricultural farms specialised either in crop production or livestock production. Today, levers are studied to help redevelop integrated crop-livestock systems at a territorial scale (Martin et al. 2016). These integrated systems offer an opportunity to diminish the use of synthetic fertiliser by redistributing manure, feed and crop residues in the farm system.

In agricultural systems there is a trade-off concerning crop residue repartition between crop and livestock production. While crop residue incorporation in the cropping system helps promoting soil fertility, crop residues can also be used in livestock production as feed or bedding material. The objective is to study different scenarios of crop residue management within the agricultural system in order to assess environmental impacts in terms of nitrous oxide (N_2O) and ammonia (NH_3) emissions.

We use a modelling approach to develop a nitrogen flow model that accounts for the nitrogen cycle within an agricultural system (here identified as a “French Small Agricultural Region”), represented by four compartments, which are livestock, crop production, grasslands and soil. We study nitrogen fluxes within each compartment and between the four compartments focussing on nitrogen fluxes due to crop residue management. We run the model to estimate N_2O and NH_3 emissions by using an emission factor approach.

We define scenarios of crop residue repartition between the crop production compartment – where crop residues are incorporated into the fields – and the livestock compartment – where crop residues are used as feed and bedding material. We then evaluate the environmental impacts of each scenario in terms N_2O and NH_3 emissions.

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Nitrogen management challenges in reducing coastal eutrophication

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Mitigate coastal eutrophication (macroalgae blooms), a widespread manifestation of excessive nitrogen loads in surface water, is challenging because it would require a drastic reduction of diffuse losses from agriculture. The objective of this study was to assess the efficiency of N agricultural loss mitigation measures applied to the coastal catchments feeding the Saint Brieuc bay (northern Brittany), heavily impacted by large “green tides”. The area is characterized by oceanic climate and mix farming with high livestock density. The set of measures tested aimed at focusing on the most critical parts of the cropping systems though preserving as far as possible the production systems and their profitability by increasing the overall NUE of the systems. These included, e.g., replacing cattle breeding based on maize silage by grass-based systems and decreasing synthetic fertilizer inputs by full recycling of animal effluents. These complex and detailed changes were simulated using TNT2, a spatially distributed agro-hydrological model (Beaujouan et al. 2002; Oehler et al. 2009), after calibration on current conditions.

Results show that the changes in agricultural management practices could reduce the N load to the bay by 31% compared to the baseline scenario. These results vary strongly between the studied catchments, mostly because of differing landuse composition and organization. These results are discussed in terms of feasibility and impacts on both the environment and the agriculture production and profitability. Their potential impacts on future mitigation policies in the area is also considered based on the action plan currently designed.

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Effect of changes in farm management on agricultural ammonia emissions and Nitrogen flows in Switzerland for 1990 to 2020

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The Swiss emission data for ammonia (NH_3) used for the CLRTAP reporting is based on calculations with the N flow model Agrammon using data from a representative stratified survey on agricultural production technique. Detailed production technique data exists for the years 1990, 1995, 2002, 2007, 2010, 2015 and 2019. Thus, the input data and the results of these calculations can be used to study the effect of changes in Swiss agriculture on emissions and the N flow in general during the past thirty years. For this contribution the NH_3 emission inventory (see www.agrammon.ch/downloads) were also combined with the results of the OSPAR nutrient balance.

From 1990 to 2020 N excretions from livestock decreased by 17.5% and N input from fertilizer was reduced by 38.3%. During the same time period the amount of N exported from agriculture increased by 26% (animal products +23%, crop products +41%). This indicates that the N use efficiency of Swiss agriculture was considerably improved. However, one also has to be aware that feed imports (concentrate) increased by 76% during the same period. In total N imports in feed and fertilizer decreased by 8% (-6971 t) while N exports from agriculture increased by 26% (10'530 t). Since 2015 N imports to Swiss agriculture in feed are larger than those in fertilizer.

NH_3 emissions from Swiss agriculture decreased by 23% from 1990 to 2020. The decrease was 21% for emissions from livestock production and manure, which can mainly be explained by changes in animal numbers (dairy cows -30%, cattle total -18%, pigs -28%, poultry +112%) and improved production efficiency (e.g. annual milk yield per cow 1990 4940 kg, 2019 7305 kg). The decrease of emissions from fertilizer and crop production was 37% and can be explained by the decrease of fertilizer use by 38% as a consequence of the introduction and implementation of nutrient balance restrictions.

From 1990 to 2020 emissions from the housing area (incl. yard) increased by 19% and those from grazing by 84% as a consequence of the promotion of more animal friendly livestock production. Major developments in this field were the change from tied housing systems for cattle (e.g. dairy cows in loose housing 1990 6%, 2019 58%), the introduction of exercise yards for cattle, more grazing (e.g. dairy cows: 1990 average grazing hours per year 1080 h, 2019 1532 h), multi-pen housing system with outside yard for pigs (1990 0%, since 2000 >50% of fattening pigs), poultry housing systems with outside access (1990 negligible, since approx. 2005 >70% of layers). Thus, the share of ammonia emissions from the housing areas to livestock and manure management (incl. yard) increased from 24% in 1990 to 36% in 2020) and the share from manure application decreased from 58% in 1990 to 44% in 2020.

The trade-off between satisfying meat demand and avoiding excess manure nitrogen at the regional scale in China

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Achieving self-sufficiency in meat at the regional scale might increase resilience (e.g., to price fluctuations), however such objective might be in contrast with the objective of avoiding locally the excess of manure nitrogen. In China, both the achievement of meat self-sufficiency and the avoidance of manure nitrogen excess are key objectives and studying their trade-off is of primary importance. The aims of this study are 1) to classify the regions of 261 regions of Eastern China (the most intensive from the point of view of crops and livestock) according their ability/inability to satisfy local meat demand and their deficiency/excess of manure; 2) to analyse scenarios of decrease in livestock number in the regions. For aim 1) we compared meat demand (based on healthy diet recommendations) and meat production (based on data of livestock abundance and productivity) as well as manure production (based on data of livestock abundance and productivity) and manure demand (based on crop data and nitrogen crop demand), considering also the fraction (30%) of synthetic fertilizer that is substituted with organic manure. For objective 2) we set livestock in each region to some key quantities: the quantity that meets local meat self-sufficiency (scenario A), the quantity that meets local manure demand (scenario B), the quantity that meets local meat self-sufficiency in case manure nitrogen is not in excess, otherwise manure nitrogen excess avoidance is given priority (scenario C). Concerning 1), our results showed that 15% of the regions analysed could meet meat self-sufficiency without any manure nitrogen excess, however in 76% of the regions meat self-sufficiency was met but while causing manure excess. Concerning 2) scenario C was the best performing, with 50% of the regions that could meet meat self-sufficiency (according to healthy diet recommendations) while avoiding manure balance. In addition, this scenario made it possible to achieve, at the level of the whole Eastern China (all the 261 studied regions pulled together), a global meat self-sufficiency and avoidance of nitrogen excess. Our study suggests that, while a trade-off exists between achieving meet self-sufficiency and avoiding excess of manure nitrogen, livestock is in excess in many regions and it is important to give priority to the avoidance of manure nitrogen excess for allocating livestock quantities in the region. Solutions must be adopted to increase the use of manure nitrogen as substitute of synthetic fertilizer in order to soften the trade-off. Further perspectives should also take into account the self-sufficiency of feed (Li et al., 2021).

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Reshaping agro-food systems for an ecological transition: Methodology and assumptions for scenario construction through the GRAFS approach.

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The GRAFS approach (Generalized Representation of Agro-Food Systems) was first designed as an accounting framework for describing N flows through past or current agro-food systems based on available statistical data. On this ground, a typology of territorial characteristics of agro-food systems, emphasizing specialization could be established.

In recent years, GRAFS evolved into a powerful modelling tool for conceiving prospective scenarios of alternative systems, including agro-ecological ones. The scenario modelling relies on some simple functional relationships assumed to govern the operation of cropping and livestock systems, involving a few parameters which are calibrated on the current situation. In particular, a simple relationship between yield and fertilization at the crop rotation scale is assumed, using Ymax (in kgN/ha/yr) as a parameter reflecting the techno-pedo-climatic context in a given territory. Similarly, protein conversion efficiency is assumed to characterize different types of ruminant and monogastric livestock systems at various levels of intensity.

Here we will discuss the assumptions behind these relationships and their validity in different regional contexts. The discussion will be mostly illustrated through the recent application of the method for designing an agro-ecological scenario for Europe at regional (NUTS1/2) resolution. This scenario shows that the expected population of Europe in 2050 could be fed without recourse either to synthetic N fertilizers or to import of feed, provided a healthier, less animal-based human diet is generalized. Emissions of greenhouse gases and ammonia as well as nitrate contamination of water would be strongly reduced.

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Investigating the scope for N surplus reductions in Flevoland using WOFOST extended with N-limited growth

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Nitrogen (N) is an important yield limiting factor in crop production throughout the world. Therefore, N is often overapplied to prevent yield losses, which causes N losses to the environment. N losses can be prevented by either reducing the N input or by improving crop management such that more of the applied N ends up in the harvestable product. Crop growth models are useful to quantify to what extent different N management practices can reduce N surpluses. One such a crop growth model that is calibrated for a large number of crop species and widely applied is WOFOST 7.2. However, WOFOST 7.2 is not capable of simulating N limited production. The aims of this study were to 1) extend WOFOST with N limited growth, 2) calibrate the model for winter wheat, 3) evaluate the model on an independent data set, and 4) apply the model to investigate to what extent N surpluses on commercial winter wheat fields in the Dutch province Flevoland can be reduced. In many crops, the maximum gross CO_2 assimilation rate declines during later growth stages due to a declining N concentration in the leaves. In WOFOST 7.2, this decline of the maximum gross CO_2 assimilation rate was taken into account implicitly by defining the maximum gross CO_2 assimilation rate as an interpolation function of development stage. In the extended version, WOFOST explicitly calculates the net gross reference CO_2 assimilation rate from the specific leaf nitrogen content. Furthermore, the model now calculates the daily N uptake and accumulations for each crop organ. Finally, the model simulates how N deficiencies affect crop growth. The model was calibrated on a detailed data set collected from field-trials conducted at various locations in the Netherlands during the growing seasons 1982-1983 and 1983-1984. The calibrated version of the model was subsequently evaluated on data from similar field trials conducted in 2013-2014 and 2014-2015. The model performed well in reproducing the growth of winter wheat in both field trials. Therefore, we could apply the model to simulate the N-limited yield and N-amounts in the grains on commercial farms in Flevoland to investigate the scope for N surplus reductions. We calculated that the area-based weighted average N surplus in winter wheat fields in Flevoland could be reduced by 71%, by reducing N input while maintaining yield and preventing soil mining. When using current N input more efficiently, and increasing yields up to the water-limited yields, the decrease in N surplus is 57%. Both strategies can also be combined. Optimal strategies vary per farm, and the model can be used to provide decision-support

Optimum N intensity in arable crop systems: a model based analysis using different GHG-indicators

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Productivity and emissions of greenhouse gases (GHG) in arable crop systems are closely linked to the Nitrogen (N) fertilization intensity. The identification of a "climate optimum" N intensity, however, is a complex task, because both parameters of crop systems depend on local soil and weather conditions and are also influenced by other management components, i.e. tillage, crop rotation and others. Despite the fact that experimental data are the pre-requisite of any analysis of GHG/productivity interactions, their regional and temporal representativity is due to capacity restrictions always limited. Mechanistic, dynamic simulation models, if properly designed, sufficiently parametrized and evaluated, have the potential to overcome some of these limitations of purely empirical data-based analysis (Räbiger et al. 2020). For the calculation of certain GHG indicators, the results of these dynamic models have to be accomplished by further, life cycle assessment (LCA) like calculations. In our study data from several joint research projects on GHG emissions from the arable crops oilseed rape, maize and wheat were collected (337 site/year/crop combinations) and used to calibrate and evaluate mechanistic soil crop simulation models in terms of direct and indirect N_2O-emissions as well as crop yield. The N-input sensitivity of these variables was evaluated by long term simulation over 295 sites using 20 years weather data and measured soil properties. In parallel the Tier I approach of IPCC and the GNOC approach were used to estimate direct and indirect (IPCC) N_2O emissions. The results were used as input parameters of a partial LCA-scheme according to REDII . From this several GHG indicators are calculated like emissions per unit yield, as well as specific GHG-reduction and a GHG balance were calculated. For the latter two, the use of the crop yield as raw material for biofuel (oilseed rape, wheat) and biogas (maize) was assumed. The results of the model calibration and evaluation indicates that mechanistic soil/crop system models are superior predictors of direct and indirect N_2O-emissions, despite the fact that still large uncertainty remains. Calculated direct and indirect emissions were in most cases lower than IPCC estimates. The optimum production intensity varied largely between the different indicators. Specific GHG-emission and yield related emission favored very low to low N intensities whereas the indicator GHG-balance led to much higher N rates.

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Dynamic monitoring of winter wheat N fertilization through the APPI-N method: an experimental evaluation

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APPI-N is a radical innovative method of nitrogen fertilization developed in recent years for winter wheat (Ravier et al. 2018, 2021). Compared to the traditionally used *balance-sheet* method, APPI-N does not require measurements of soil mineral N and a target yield forecast. It is based on the dynamic monitoring of crop Nitrogen Nutrition Index (NNI) from the end of winter to flowering stage, and on an NNI threshold trajectory that should not be crossed without risking yield loss. The objective of this new method is to maximize the Nitrogen Use Efficiency (NUE), through 2 main pillars: *(i)* accepting N deficiency period at the beginning of crop cycle, that is not detrimental to yield and protein content; *(ii)* rely on climatic conditions to decide N application dates and rates, by objectifying the risk of drought, which allow to maximize the valorization of nitrogen.

Although the APPI-N method seems promising to improve NUE, an experimental evaluation of its potential was still lacking. In the SOLINAZO project, we tested the APPI-N method and compared it to the balance-sheet method on 36 plots between 2018 and 2021. NNI was monitored by an indirect indicator (chlorophyll meter), grain yield and protein content were measured, and the NUE was estimated with non-fertilized control plots. Finally, in order to assess economic and environmental performance of APPI-N, the partial margin and greenhouse gases (GHG) emissions were quantified.

Results showed (i) a delay of the first N application (on average 20 days later than for the balance-sheet method) and a reduction of the total number of applications; (ii) a reduction of total N rate without significant changes in yield or grain protein content; (iii) a reduction of nitrogen losses and of GHG emissions.

The APPI-N method seems promising to use nitrogen is a more efficient way: it gives users the possibility to follow plant needs and to have a direct feedback on their fertilization actions. It can also be easily adapted to technological advances, especially to monitor NNI in a less time-consuming way (visible imagery, satellites, etc.). Nevertheless, its radically innovative nature challenges farmers' habits and requires learning new ways of thinking.

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Effects of crop residue management on N-balance and N_2O inventories on European croplands. A multi-modelling evaluation

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Farmers are encouraged today to increase their usage of organic amendments in the aim of increasing soil C storage and limit the dependence by mineral N fertiliser (Rumpel et al., 2019; Smith et al., 2016). Unharvested crop residues act as organic manure, but have a priming effect on soil microbial activity and therefore on greenhouse gas (N_2O) emissions. This study aims to estimate the effects of crop residue management scenarios on the whole N balance and N_2O emissions on European croplands.

Four different crop residue managements have been evaluated: a usual-as-business scenario; exported; incorporated; left on soil surface. Representative crop successions and N fertilisation amounts were simulated on a grid of 0.25° × 0.25° spatial resolution over EU-27, from 2000 to 2020. Three biogeochemical, i.e. CERES-EGC, LandscapeDNDC and LandscapeDNDC-MeTRx, have been used in an ensemble approach.

Our results shown that N balance has a slight positive gap for the business-as-usual scenario (+2.9 ±4.0 kg N ha^{-1} y^{-1}, or +226 kt N y^{-1}), while is negative (-4.9 ±4.3 kg N ha^{-1} y^{-1}, or -667 kt N y^{-1}) when residues are exported. The entire crop residue restitution will produce a net N excess, potentially leading to diffuse sources of pollution. In fact, incorporating or leaving crop residues on soil surface presents a similar amount of N surplus (about +17 kg N ha^{-1} y^{-1}, or 1950 kt N y^{-1}), whereas soil C stock were greater when residues stand on soil surface.

N_2O emissions in Europe appear to be significantly driven by the native carbon content in the soil, and the amount of added residues. After 20 years of continuous crop residue management in the different scenarios, N_2O emissions increased by +27 % and +12 % for the incorporation and the surface management, respectively, compared to the business-as-usual scenario. They decreased by -14 % when residues were exported.

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Use of Random Forest to predict the main factors that affects ammonia volatilization in Mediterranean climate cropping systems

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Ammonia (NH_3) volatilization is a major pathway of nitrogen (N) loss in agricultural systems, causing a reduction in N fertilizer efficiency, it is a precursor of particulate matter formation, and after deposition contributes to soil acidification, eutrophication, and loss of biodiversity. Although mitigation strategies have been developed and implemented to reduce NH_3 volatilization, their efficiency may vary on a local and regional scale, as ammonia volatilization depends on edaphoclimatic conditions and crop management. Considering the uniqueness of Mediterranean cropping systems, it is necessary to evaluate these mitigation strategies and establish the main factors that affects NH_3 volatilization under these specific conditions. We compiled 29 papers (indexed in Web of Science) estimating cumulative NH_3 emissions and emissions factor (EF) following N fertilization, and constructed a database that includes 247 field experiments from Australia (n=17), California (n=25), Chile (n=23), and the Mediterranean basin (n=182) during the period 1998 to 2021. We used machine learning method Random Forest (RF) approach to extract the most important drivers. RF not only predict the NH_3 volatilization and EF, but also ranks the input variables on the basis of their importance for the prediction. With this research, we aim to identify the edaphoclimatic and crop management variables that influence NH_3 emissions and determine the suitable mitigation strategies for the Mediterranean climate. Our results indicate that N application rate and soil pH are the main factors influencing ammonia volatilization.

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The Manureshed Initiative: Reconnecting animal and crop production to reduce fertilizer reliance

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Decades of agricultural intensification have resulted in the separation of crop and animal agriculture in many nations, such that the production of animal feeds and animal feeding are conducted on separate farms, which are often great distances from each other. Animal feed production relies heavily on commercial fertilizers while feeding operations produce vast amounts of concentrated manures that must be managed. Consequently, certain places have a surplus of manure nutrients while others are in nutrient deficit and require fertilizers for crop and range production. Recently, the global shocks of the COVID-19 pandemic and Russian-Ukrainian conflict have interacted with these structural problems, laying bare vulnerabilities in agricultural supply chains and exacerbating food prices and concerns over food security. Queue the "Manureshed" Initiative, which develops and tests innovative approaches to recycle nutrients between animal and crop production systems, turning manure, which can be a liability to animal producers, into a resource for crop producers. Led by scientists in the Long-Term Agroecoystem Research Network (LTAR), this comprehensive research program takes advantage of extensive data systems of the federal governments of the United States and Canada, stakeholder networks, and innovative technologies to identify and promote opportunities for manure nutrient recycling across agricultural supply chains. We envision coordinated manureshed systems powered by diverse actors who collaboratively manage manure resources based on system-level optimization, and who prioritize the removal of barriers to manure recycling. In this presentation, we discuss the manureshed vision, the social networks underlying manureshed management, barriers to manure recycling, and examples of industry-specific solutions to overcoming those barriers. We will close with a discussion of how this initiative may apply in and among nations in Europe.

Maximizing food production while minimizing inputs in three French farming systems: studying optimised compositional changes from a nitrogen perspective

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European farming systems (FS) are currently dependent on nitrogen (N) synthetic fertilisers and protein concentrates supplies while the impending global peak oil could lead to input supply constraints. Thus their resilience, i.e. their capacity to maintain food production facing these challenges, is questioned. Input autonomy is identified as increasing resilience but it involves trade-offs: e.g., a decline in inputs supplies could lead to a decline in food production. The aims of this study were, from a N perspective to (1) explore the trade-offs between food production (crop- and animal-sourced) maximisation and input supplies (synthetic fertilizer and feed) minimisation and (2) to explore crop-livestock compositional changes that, with respect to current composition, best alleviate this trade-off. We selected three FSs with different crop-livestock compositions: (i) field crops (Plateau Picard), (ii) intensive dairy cattle and monogastrics (Bretagne Centrale), (iii) semi-extensive ruminants (Bocage Bourbonnais). We mobilised a FS N biomass flow model (Pinsard et al., 2021) and used multi-objective optimisation, formulating two scenarios: (1) maximisation of animal- and crop-sourced food productions, and minimisation of synthetic fertilizer and feed supplies (with constant crop productivity); (2) maximisation of food productions imposing zero input supplies (potential decrease of the crop productivity). In both scenarios, we found pairwise trade-offs between the objectives. The trade-offs between the two types of food production differed in intensity according to the current shares of permanent grassland and crop for food areas. In scenario (1), the optimized solutions that maximise total food production while minimising inputs were few in number and close to the current levels of food production and input supplies. In these solutions, the monogastric number increased at the expense of ruminants due to their better N use efficiency, except in the semi-extensive ruminant FS as permanent grassland could only be valorised by ruminants. In scenario (2), the optimized solutions that maximise total food production (compared to current levels without inputs) showed more than a 90% decrease in livestock number, and increase in areas of dry legumes and cereals for food. As a result, the feed-food competition for biomass use decreased significantly (below 5% in the three FSs in median). Our results showed that livestock composition redesign, coupled to crop productivity decrease, are essential levers to alleviate the trade-off between food productions and input supplies. A shift in diets towards reduced animal protein intake as well as reduced losses in the food system would further increase resilience to inputs supply constraints when implementing the identified compositional changes.

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Ley grazing in Integrated Crop Livestock Systems (ICLS) for sustainable dairy systems in NW-Europe

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Recent intensification in European agricultural production is accompanied by serious environmental trade-offs questioning sustainability of current specialized production systems for both all arable cash crops and animal products. Integrated Crop-Livestock Systems (ICLS) are considered as a strategy towards ecological intensification. Under the maritime conditions of North-west Europe, ruminant-based ICLS are discussed as an alternative to specialized dairy and all arable systems. This is the background for the interdisciplinary project: "Eco-efficient pasture based milk production" established in 2016 at Kiel University's research farm Lindhof in Northern Germany. The project focusses on an approach fulfilling all relevant ecosystem services linked to dairy systems: high quantity and quality of agricultural commodities; low nutrient surpluses for clean water; low carbon footprint for mitigating climate change and contributions to agro-biodiversity. Comprehensive data are presented based on a 100 spring-calving Jerseys/crossbred dairy herd on a former all-arable farm as an alternative to traditional specialized systems. Records collected are: forage yield and quality, nitrogen fluxes, GHG-emissions, milk production and quality as a function of the diversity gradient in the botanical composition of grazed swards.

The results proof the capability of a rotational ley grazing system based on spring calving with high milk performance per ha (land use efficiency is comparable with the very best 10% of commercial dairy farms [control group] in the state) combined with very low environmental footprints (carbon footprint of 0,63 kg CO_{2eq} per kg ECM is 55% of the control group and nitrogen footprint of 5 g surplus per kg ECM is 41% of the control group). Additionally, intensively grazed multispecies leys offer an attractive feed source for bumblebees and thus provide all aspects of ecological intensification. Calculating the avoided social costs of this system compared to the control group ends up in figures of around 300 € per ha due to avoided nitrogen losses to the environment (according to the European Nitrogen Assessment Report) and 200€ per ha due to avoided CO_2-emission (according to Carbon Credit pricing for the year 2030). European agricultural and environmental policies should thus support a wider implementation of ley systems in Europe.

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Modelling nitrogen flows on African smallholder farms; many challenges and some solutions

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The limited availability of reactive nitrogen (N) constrains crop production on many smallholder mixed crop-livestock production farms in Africa (Elrys et al, 2019). Smallholder farms account for >95% of farms in Africa and are challenged to feed a rapidly increasing population (Graeub et al., 2016). Identifying options to increase the production of these farms is thus a priority. This increase can either be achieved by increasing the efficiency of N use within the farms or through the strategic use of imports such as fertilizer or livestock feed. Despite their small scale, farms are typically diverse, containing both ruminant and non-ruminant livestock, and a broad mixed of crops. This results in a complex network of internal N cycling which is difficult to quantify empirically. Models offer complementary solution but face significant challenges in an African context. Compared to most developed countries, the crop rotations are more complex (inter-row, mixed species and double cropping), there is a greater use of crop residues as livestock feed and there are fewer scientific studies of the crops used and N losses from manure management to support model parameterization. The FarmAC model (www.farmac.dk) was constructed with intention of minimizing the need for crop, soil and livestock parameters, while retaining sufficient process detail that the investigation of measures to increase N use efficiency and recycling remained feasible. Here, we will use examples of smallholder mixed crop-livestock farms in Senegal and Kenya to illustrate the challenges encountered when modelling N flows on in these systems and how most but not all can be overcome.

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When the baseline meets the present: reactive N emissions in wildlife- *vs.* livestock-dominated African landscapes

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Pastoralist livestock in Old World savannas has been estimated to emit a significant share of the world's livestock reactive N emissions (especially N_2O emissions from grazing). However the disappearance of such systems may not necessarily lead to a net reduction on reactive N emissions globally - potentially, there could be an overtake of grazing ecosystems by wild herbivores (Manzano & White, 2019) and hence, a replacement of reactive N emissions. In this study we analyzed the scenario of a tropical savanna landscape that is intensively used by grazed livestock, but which has the potential to be rapidly recolonized by wild herbivores in the case it is abandoned. For this, we compare estimated animal-sourced reactive N emissions per area unit from the Serengeti Ecosystem, a wildlife-dominated savanna, with the adjacent Loliondo Game Controlled Area in Tanzania, an agricultural land with similar ecological characteristics but under pastoralist use. We applied different approaches to estimate reactive N losses from herbivore animals. Wildlife showed average reactive N emissions of about 5% more than those from pastoralism areas (Serengeti: 0.081 kg N_2O-N/ha yr; 4.34 kg NH_3-N/ha yr; 4.96 kg NO_3-N/ha yr vs. Loliondo: 0.077 kg N_2O-N/ha yr; 4.15 kg NH_3-N/ha yr; 4.75 kg NO_3-N/ha yr). Our results suggest that, for the case of the Serengeti ecosystem, strategies aiming at abandoning grazing lands would not achieve any reduction in reactive N losses present in the atmosphere or water courses. Our work is limited by the large uncertainties absolute emission numbers may be subjected to, since both wildlife emissions or emissions from extensive systems in Africa have still not been sufficiently studied; and by rangelands in other continents being subjected to different ecological realities or to farming systems under more intensive management (livestock under enclosure). However, our estimates indicate that reactive N emissions from pastoralism may sometimes be in the same order of magnitude than that from wildlife. Assuming that 100% of N reactive losses in extensive livestock system are anthropogenic. i.e., leading to increased N loads in the atmosphere or in global water bodies, is generally mislead. We should account for these "baseline" N reactive emissions, and be cautious on pushing for any measures that reduce pastoralism in sub-Saharan Africa or in many Asian countries in the name of reducing reactive N losses to the atmosphere or water bodies.

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Optimizing the nitrogen management on the farm level by using proximal and remote sensing

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Nitrogen surpluses result from excessive N-inputs. These result from intensive, non-land-based animal husbandry, leading to a high accumulation of organic fertilizers or too high mineral N fertilization. These pollute the hydro- and atmosphere.

Excessively high inputs must be recorded and evaluated via farm-gate or area-related balances. N fertilization must be based on demand and take into account the nitrogen present in the soil at the beginning of vegetation as well as mineralizable nitrogen, and must also be based on realistic yield expectations. The latter must be viewed critically since yield maximization is practiced in many regions, often leading to N loads.

N status at the beginning of vegetation cannot be assessed by near- and remote sensing, whereas N mineralization can be assessed either during vegetation or as post-hoc information. Crop N status during vegetation can be captured relatively reliably by remote sensing and is particularly good at weaker to moderate biomass growth, while this becomes more difficult at very strong biomass growth or excessive N supply.

For N fertilization, N status must be recorded before N fertilization; the more frequently a crop is fertilized during vegetation, the more suitable remote sensing is. However, since fertilization is also frequently applied at sowing or early vegetation stages, only a retrospective assessment can be carried out.

Spectral detection of the N-status, e.g., by nitrogen indices, does not directly lead to an optimized fertilization recommendation because the N-status is not detected absolutely, and the relationship between spectral information and biomass status can also vary, and variety-specific influences are present. Research to date has focused too much on capturing N status exclusively, so in the future, many more algorithms must be provided to optimize N fertilization. Approaches such as the GreenWindows or the ramped calibration technique are suitable for this purpose, based on the fact that relative differences are simplified into N recommendations due to incremental N fertilization.

So far, mainly terrestrial systems are used in agricultural practice, but only to a limited extent. Tractor-based sensors are particularly well suited, and manual systems are used less frequently. Nevertheless, a very good potential is seen in low-cost, simple, e.g., smartphone-based systems. Satellite-based sensing of biomass, N status, or yield has the advantage of spatial scalability; its potential and limitation are shown.

Remote sensing can help optimize N fertilization and allow reducing N surpluses. However, previous approaches are often too science-based and require more effort to integrate into agricultural management.

Multi-platform remote sensing of nitrogen status and leaching from agricultural fields with random forest regression approach

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Advances in satellite- and drone-based technologies, such as increased spatio-temporal and spectral resolution, in combination with improved computational algorithms, including machine learning, have proven to be useful tools altogether in assessing crop nitrogen (N) status and facilitating precision agriculture. However, it remains challenging to accurately determine in-season crop N status and detach split fertilization from residual soil N prone to losses during (gaseous emissions) and after the growth season (leaching). We conducted a three-year potato field experiment on sandy soil in Denmark (Peng et al. 2021) and determined single-shot in-season plant N uptake (PNU), concentration (PNC) and N nutrition index (NNI; based on the critical N dilution curve). Multispectral data obtained by spaceborne- (Sentinel-2), air- (unmanned aerial vehicle, UAV) and ground (handheld Rapidscan) platforms were correlated with the measured variables, with random forest machine learning regression achieving very high prediction accuracy of < 10kg N ha^{-1} uncertainty. We also measured nitrate concentration in the soil solution at the end of the root zone, and these measurements showed on average consistently lower values for the split- (16-42 ppm) compared to the full (20-57 ppm) fertilization strategy, with reductions reaching 37% at the peak of the leaching season in November. The approach of accurately detecting plant N requirement and supplying fertilization accordingly, which leaves little substrate of reactive N pool in the soil during and after the growth season is promising for the smart farming industry in the struggle to limit nitrous oxide emissions and N leaching by keeping soil nitrate concentration at low levels. More work should also be done on bridging N deficiency from other abiotic stresses, especially drought, in order to further improve N application recommendation.

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Improving Nitrogen Use Efficiency through Precision Nutrient Management in Winter Wheat and Maize Cropping Systems

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Effective nitrogen (N) management strategies for cereal crops is a cornerstone of agricultural systems that are profitable, resilient, and avoid environmental impairment. Winter wheat and maize response to N fertilization, N loss pathways, and nitrogen use efficiency (NUE) vary greatly across national, regional, and sub-field scales. Multiple studies were conducted across Wisconsin, USA to assess N fertilization strategies in winter wheat and maize. Crop spectral reflectance, soil moisture and temperature, and weather data were collected throughout the growing season. Soil and plant samples were collected important growing stages to determine N uptake, NUE, and N need at each stage including physiological maturity. Nitrogen rate treatments were applied as split plots across soil-test phosphorus and potassium (STPK) levels corresponding with interpretation classes of low, optimum, and high. Considerable difference between economic optimum N rates (EONR) and NUE was seen across site-years for winter wheat and maize. Nitrogen use efficiency was affected by soil N concentration at critical growth stages, soil N loss potential, and fertilization strategy. In maize, the EONR and NUE was affected by STPK level. Prediction of N requirement for winter wheat was improved by using normalized difference vegetation indices (NDVI) taken at 5 Zadock's growth stages prior to N application and soil profile N. Winter wheat grain yield, partial nutrient productivity, agronomic N fertilizer efficiency, and fertilizer N recovery efficiency were improved by coordinating N applications rates with N requirement informed by canopy sensors and soil N testing. Across all winter wheat site-years, improvements of 7.5 kg grain kg^{-1} N applied was achieved with a 0.8 Mg ha^{-1} grain yield increase with sensor and soil-informed N rates. Maize grain yield and NUE response to N fertilization was improved two-fold when STPK were at Optimum levels or greater compared to a Low interpretation class. Nitrogen fertilizer rate described a low proportion of grail yield and NUE variation (R^2 = 0.31) when STPK levels were Low compared to Optimum (R^2 = 0.83). Nitrogen requirement of maize was reduced by 74 kg N ha^{-1}, grain yield increased by 3.2 Mg ha^{-1}, and profitability was increased by $248 ha^{-1} when STPK was maintained in the Optimum category. The findings from multiple studies of winter wheat and maize cropping systems indicate that considerable improvement in NUE is possible through the use of site-specific management strategies which focus on sensing N need at critical growth stages, monitoring soil N, and maintain STPK levels that promote balanced plant nutritional demands. These improvement have the potential to scale up from the management unit to the field, or physiographic region.

A detailed bottom-up characterisation of the nitrogen flow evolution of the Spanish Agro-Food System at the province and national level

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The improvement of the agro-environmental performance of the agro-food system requires integrated approaches and not just isolated sectorial actions. As a first step, a detailed characterisation of the system is crucial for effectively identify where and how to act on the system to achieve the desired outcomes.

In this study, a thorough characterisation of the Spanish agro-food system was done by describing N flows. The province level (with mean surface of ~1Mha) was selected, as it represents an adequate scale of interaction between the different compartments of the agro-food systems: grasslands, livestock, crops, and people, while also being an administrative division of the national territory.

Here, a detailed bottom-approach has been carried out for calculating the N flows for the 1990-2015 period, at the province and national levels. Province information (of 50 provinces) regarding (1) Livestock production, with a complete description of the N ingestion (distinguishing 99 feed types) and N excreta for each cohort (e.g., 24 for bovine or 14 for porcine), and N contents of livestock products. We identified the net import of each specific feed. (2) Crop N fertilisation (synthetic, manure and urban) and production, for 118 crops, differentiating between rainfed, irrigated and greenhouse systems (3) Human N consumption including tourism; and (4) N deposition and biological N fixation in crops and grasslands.

The availability of vegetal protein in Spain increased from ca. 1100 to 1400 GgN/yr in the 1990-2015 period. In 2011-2015, crop and grass production and net import of food and feed accounted for 48%, 29% and 24% of this protein, respectively. Only 8% of this available protein is allocated to direct human consumption while the rest is ingested by ruminants and monogastric animals (54 and 36%, respectively).

The analysis of the N flows at the province level reveals quite contrasting types of agro-food systems regarding the main flow fuelling the whole system: 1) N inputs from grasslands; 2) net import of feed; 3) synthetic fertilizer with predominance of arable crops 4) synthetic fertilizer with predominance of woody crops. The approach is particularly useful to support local systemic transformation to comply with the Farm-to-Fork strategy from the European Union.

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Nitrogen sources and fates in the agroecological transition. Integrated scenario modeling combining production and consumption measures in Spain

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The disruption of the nitrogen (N) cycle is one of the main processes involved in environmental degradation by agro-food systems. The situation in Spain is particularly worrisome, with severe water and air pollution problems linked to NH_3 volatilization and NO_3^- leaching, respectively, in combination with a heavy dependence on synthetic fertilizers and imported feed. In this work, we have modeled the effects of a complete reorganization of the Spanish agro-food system with different combinations of measures, including: production-side measures such as generalization of agroecological practices and extensification of livestock breeding, structural changes such as reconnection of production and consumption (including eliminating feed imports) and food waste reduction, and consumption-side measures such as increased legumes (3x) and vegetables (2x) consumption while reducing meat and milk consumption in the human diet to match the new animal production. The assessment includes soil N and C balances at the provincial scale and trade balances and human diets at the national scale. In this work we focus on the changes in the sources and fates of N, although additional impacts have been assessed.

In the agroecological scenario with dietary changes, ~1000 GgN from synthetic fertilizers and 420 GgN from imported feed inputs are estimated to be avoided while maintaining sufficient food protein supply, reducing the share of animal protein from 64% to 46%. Nitrogen fixation in cropland doubles, including 130 GgN additional N from the expansion of grain legumes over fallow land and 84 GgN additional N from cover crops. Recycled N is also enhanced, including 41 GgN from avoided burning of crop residues, and 40, 22 and 138 GgN from improved recovery of agro-industry residues, urban waste and human excreta, respectively. In addition, the increase in soil organic C sequestration is related to the sequestration of 198 GgN. Crop and livestock N production decrease by 4% and 50% to 814 and 116 GgN, respectively, while the 87% reduction in NO_3^- leaching (to 64 GgN) and 41% in NH_3 volatilization (to 306 GgN) allow getting N pollution to levels lower than the international limits that Spain currently surpasses. In addition, these effects on the N cycle are combined with attaining a negative food consumption C footprint, a 80% reduction in non-renewable energy, and a 95% reduction in the land footprint of imports.

Nitrogen management in food production is a key driver of the energy budget of agricultural systems

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Unlike natural ecosystems, agro-food systems involve human control of biogeochemical flows and the use of machinery, which materialize into invested nutrients and energy via technology and production patterns. Because proteins are essential in food and their production relies on reactive nitrogen (N), global food production is conditioned by N availability.

However, the relationship between N use patterns and the energy balance of agro-food systems is barely addressed in the scientific literature. Though, N management has major energy implications regardless of the fertilization regime – organic or industrial. In organic agriculture, nutrients are usually the limiting factor of production, thus N loss jeopardizes photosynthetic activity and, thereby, limits the energy output of agriculture. Under industrial fertilization, N limitation on crops growth is possibly eliminated, but due to the high embodied energy of N fertilizers, N loss equates to significant dissipation of invested energy. In both cases, N harvest involve on-farm energy requirements depending on agro-food systems design and production practices. Consequently, N use patterns play a key role in the energy balance of agro-food systems and have been reported as a major driver in agricultural surplus transitions over time (Harchaoui and Chatzimpiros, 2018).

Livestock is a particularly significant component in N and energy balances of agro-food systems. Inevitably, the higher the amount of feed in support of livestock production, the higher the energy dissipation through feed to food conversion and also the amount of potential N loss during feed growth and livestock N excretion. Naturally, many of these aspects depend on the functional integration between crop and livestock systems, which is also affects N loss abatement strategies.

This paper examines N as a driver of the energy functioning of agriculture. We build a model integrating N harvest and energy invested in relation to N use efficiency in land compartments, field work, feed to food conversion efficiency, manure N management, dietary choices and biowaste N return to agriculture. We explore past trends based on historical data for France (Harchaoui and Chatzimpiros, 2018) and provide theoretical developments in support of prospective agro-food system modelling. The results enable to better understand agricultural dynamics and transitions in relation to N loss abatement and changing energy and environmental challenges.

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Assessing nutrient fate from terrestrial to freshwater systems in Fuxian Lake Basin, China

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Abstract: The agricultural sector, while crucial for human development and well-being, is a major contributor to environmental stress. Emissions from this sector have become an important source of nitrogen (N) and phosphorous (P) for freshwater systems, bringing an increased risk of eutrophication. To control agricultural runoff, decision-makers usually consider the importance of pollutant contributors before formulating environmental strategies, which requires nutrient models to quantify corresponding nutrient fate. However, nutrient fate is hard to model due to the complexity of nutrient interaction and transport process. Especially in rural regions, the data required by current distributed models are mostly unavailable or inaccessible. To assess the nutrient contribution from different emission sources to freshwater, we adopted a localized Loading Simulation Program C++ (LSPC) model to simulate total nitrogen (TN) and ammonia nitrogen (NH3-N and NH4-N) in 52 inflow rivers of the Fuxian Lake Basin in China. The results show that agricultural activity is the main contributor for diffuse N, generating 42% and 49% of diffuse TN respectively. Besides, long-term accumulation of fertilizers has led to excessive N and P release from farming land. Promoting a 10% increase in N use efficiency (NUE) in the long term can reduce more than 5% N export to Fuxian Lake due to the reduction of fertilizer application and soil release.

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Ammonia measurements for ecosystem protection: considerations for the design of a monitoring network

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Ammonia impacts nitrogen-sensitive ecosystems, leading to eutrophication and thereby loss of biodiversity. In addition, direct uptake can have detrimental effects for vulnerable species such as lichen. Next to its impact on ecosystems, ammonia plays a critical role in the formation of fine particulate matter, affecting human health.

Despite existing ammonia mitigation efforts, observations indicate that average ammonia concentration levels in Europe have been rather constant or even increasing in the last decades. This is in contrast to the decline of pollutants regulated under the EU Ambient Air Quality Directive (AAQD), such as nitrogen oxides. While ammonia emission reduction targets are laid out in the EU National Emission reduction Commitments Directive (NECD), a monitoring of ambient ammonia is demanded neither under the NECD nor the AAQD. However, monitoring of its ambient concentration is important to assess the effect of ammonia emission reduction policies. In Germany, air quality monitoring is performed by federal states, a national ammonia monitoring network that focuses on ecosystem protection does not exist.

In this presentation, we investigate the underlying questions that are vital for designing an ammonia monitoring network for Germany: (1) What are the goals of an ammonia monitoring network and how are they viewed in the legal context for Germany? (2) What are the criteria for the selection of monitoring sites, considering the monitoring objectives, site representativeness, logistical aspects and the use of existing networks? (3) What are the demands on measurement methods regarding their performance and operation in the field? (4) Finally, the combination of in-situ measurements with satellite observations and model simulations is discussed.

While the presentation focuses on the situation in Germany, considerations on the site selection are presented in a general way and may be transferred to other countries or regions.

Temporal variations of atmospheric ammonia revealed from space: from long-term global trends to weekly cycle and intraday variability

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Ammonia (NH_3) is widely recognised as a major primary pollutant, deteriorating water, soil, and air quality. While the importance of monitoring and regulating atmospheric NH_3 emissions has been underlined for decades by experts in the field and endorsed or ratified by a multitude of international organizations, it is only recently that the issue is making its way onto the political agendas. Over a decade ago, it was discovered that high-resolution infrared satellite sounders can measure atmospheric NH_3, leading to major advances in our understanding of this atmospheric compound and its sources, and to new possibilities for benchmarking or enforcing regulations.

Currently, several satellite instruments on polar orbits measure NH_3 global distributions twice a day. Here, we use the long-term daily NH_3 time-series available from the Infrared Atmospheric Sounding Interferometer (IASI) mission (end of 2007 up to now) to derive global, regional, and national trends. Reported national trends are analysed in the light of changing anthropogenic and pyrogenic NH_3 emissions, meteorological conditions, and the impact of concomitant sulphur and nitrogen oxides emissions.

For the first time, the presence of a weekly cycle in the atmospheric NH_3 burden is identified from space over north-western Europe. The weekend effect highlighted here presents a strong seasonality due to agricultural activities and associated regulations. Ground-based measurements from the Dutch National Air Quality Monitoring Network corroborate our results.

Finally, we present the first observations of NH_3 from the Geostationary Interferometric Infrared Sounder (GIIRS) onboard the Chinese FY-4A satellite. GIIRS measures almost all of Asia ten times per day. We analyse the daily cycle of NH_3 over two small regions in Pakistan and China, and how it varies across different seasons.

Comparison between hyperspectral indices and traits derived from biophysical model for assessing winter wheat genotypes performance

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Nitrogen (N) is the nutrient most limiting in agricultural production around the world. However, this resource has been over-applied in agriculture for decades, increasing the environmental and economic costs. Remote sensing is a valuable tool to increase sustainability in farming systems; nevertheless, specific strategies to improve N fertilization should be better addressed. The main goal of this work is the assessment of nutritional status, and the detection of different genotypes performance by coupling radiative transfer models (RTM) with machine learning (ML) approaches in wheat (*Triticum aestivum* L.) crops. For that, two field experiments with barley–wheat and pea–wheat crop rotations, three wheat genotypes (Cellule, CH-Nara and Nogal) under two water levels and different N treatments were conducted in central Spain and west Switzerland over 3 years (2018-2020 and 2019-2021). We measured leaf chlorophyll content with SPAD® or Dualex® leaf-clip sensors. Whilst we performed the canopy reflectance (400-1000 nm) with a handheld spectroradiometer at three different wheat growth stages. Additionally, at harvest stage, we estimated the grain yield (GY) and grain N concentration (GNC). We used a hybrid ML method, which combines the simulated reflectance derived from PROSAIL model with ML algorithms, for retrieving chlorophyll (Chl) and leaf area index (LAI). Additionally, different vegetation indices (VIs) were calculated through hyperspectral canopy reflectance. At the beginning of stem elongation, GY was better assessed by the canopy chlorophyll content index (CCCI) in most genotypes in both locations. At the end of stem elongation and flowering, all VIs and plant traits retrieved by the hybrid method obtained higher coefficient of determination (R^2) than SPAD® or Dualex® readings in both locations (except Nogal genotype at flowering the first experimental year in Spain). However, we highlight that the relationships between traits and VIs with GNC showed great variability between years, locations and genotypes. Moreover, the Chl, LAI retrieved by the hybrid method and CCCI showed the best differentiation between genotype performance in both locations, showing the genotype Cellule higher response than Nogal (Spain) and CH-Nara (Switzerland). This study highlights the ability of plant traits retrieved by RT models through hybrid ML method and VIs to assess GY and detect different performances in winter wheat genotypes. However, for GNC assessment more research is necessary.

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Future Farm: Technology solutions for improved nitrogen application in Irrigated Cotton, Australia.

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Optimising the use of nitrogen (N) fertiliser is an important strategy for Australian cotton growers. The Future Farm project was conceived to improve farmer confidence in targeted N management through automated sensing and decision support systems. Future Farm will automate the processing of crop and soil N information from data acquisition, analysis, to the formulation and implementation of decision options. Nitrogen fertiliser typically represents 20% of variable costs in irrigated cotton production (Scheer et al. 2022), and is a major determinant of profitability and productivity. There is a wide range in N fertiliser being applied across the Australian cotton industry (e.g. 18-519 kg N/ha in irrigated systems) and these applications are not correlated with yield. To optimise N use efficiency we can use the tools of Precision Agriculture to deliver on the 4 Rs – putting the right amount of the right product in the right place at the right time. Traditional N management trials assess the yield response of cotton assuming fields without considering the variability in soil chemical and physical properties across the entire field. The use of management zones and optical sensors (satellite and ground based) offer an economically viable alternative. Reflectance data collected from these optical sensors can also be used to calculate Vegetation Indices (VIs), providing rapid and vital information on crop development at a fine scale and over a large area which informs N management. The objectives of Future Farm include an evaluation of freely-available 10 metre resolution satellite data (Sentinel-2) to estimate petiole NO_3-N, leaf N and lint yield across management zones using VIs. We also compared VIs derived from Sentinel-2 and a very high spatial resolution ground based optical sensor (Crop Circle). We found that VIs can estimate differences in crop N status within management zones. However, a multivariate approach that considers soil moisture, canopy structure and soil background reflectance is required to accurately predict leaf N, petiole NO_3-N and lint yield across the entire field. The sensor comparison has found that VIs derived from Sentinel-2 provide similar results and reflectance patterns to the Crop Circle. Sentinel-2 can therefore be used as a cost-effective source to estimate N status and inform N management decisions. Future Farm will significantly improve the way in which soil and crop sensors are used to inform decisions about the amount and timing of N inputs to maximise productivity and profit.

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Proximal sensing by RGB camera to assess N content at plant leaf

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We proposed the development of this tool for sensing nitrogen (N) in various field crops. An algorithm was programed and calibrated with machine learning software and multiplied DSSAT(Hoogenboom et al. 2019) dry matter (DM) output by %N from a photograph. The data replicated laboratory measurements with linear Lab vs Camera model that displayed a unit slope with $r^2 > 0.8$. Increase of DM with time was successfully replaced by days after emergence (DAE) and used as abscissa for a modified equation of critical nitrogen level (Nc) that decreased gradually from about 6% to 2% with DAE that increased from 0 to more than 100 DAE. The determination of N application based on the smartphone photograph proved to be useful by saving on time and expenses for growers who have access to smartphones and can use them for N application and management.

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Removing soil background to improve the prediction of wheat nitrogen traits with UAV imagery

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As global food demand increases, it becomes necessary to improve the productivity and quality of cereals. In particular, winter wheat (Triticum Aestivum L.) needs to maximize grain yield and quality by applying the minimum amount of fertilizer. Therefore, improving the management of agricultural systems is essential for achieving high N efficiency.

Remote sensing provides real-time monitoring of N wheat conditions and allows significant data collection for decision making. Recently, sensors onboard in unmanned aircraft (UAVs) and drones have showed high efficiency in monitoring and assessing vegetation. This work introduces a method to reduce the effect of soil background to improve the reliability of high-resolution images for wheat surveillance.

The experimental area in Aranjuez, Spain, is composed of four areas (S1, S2, S3, S4), with 133 plots. Different nitrogen doses were applied to create high experimental intra-variability. In each plot, wheat traits were measured at harvest. UAVs were flown in stages GS32, GS39, and GS65 to ensure correct crop monitoring. Then four VIs (NDVI, MSAVI, NDRE, and BRI) were selected based on sensor spectrum information and their ability to estimate wheat characteristics. A series of threshold values were calculated based on the percentages of the VIs distribution. Subsequently, a sequential cutting method (TVO) was implemented to remove background pixels. Finally, we performed a linear regression between each VI segmentation and wheat characteristics to analyze the determination coefficients (R2) and the mean square errors (RMSE).

Our results show that NDVI, MSAVI, and NDRE can predict wheat characteristics using sensors on UAVs. The optimal threshold values vary between 0.1 and 0.3 depending on the VI employed and the wheat trait analyzed. The TVO method improved yield estimates, especially in the growth stage of stem extension (GS32). However, the TVO method does not significantly improve protein content estimation in anthesis (GS65). MSAVI and NDRE achieved high R2 in yield estimation, being 0.58 to 0.72 for GS32 and 0.63 at GS65. Overall, our results suggest that soil background reflection is an important element of UAV images, introducing uncertainty into grain yield and quality estimation based on VIs, and in most cases, TVO minimizes soil effects.

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Wheat nutritional status estimation based on chemometric methods combining proximal and UAV-based measurements

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To increase Nitrogen (N) use efficiency (NUE), real-time crop N status assessment is important to adapt the N fertilizer rate by applying the right amount, at the right time, and at the right place to match crops' demand and avoid environmental losses. In this context, proximal and remote sensing offer good opportunities to optimize N fertilization. After evaluating the ability of proximal and unmanned aerial vehicle (UAV) based measurements to monitor wheat N nutrition index (NNI) during crop growths, we aim to study the interest of chemometrics methods to combine proximal and remote sensing measurements to increase the accuracy of NNI monitoring.

During three growing seasons (2020 to 2022), three field-trials showing various patterns of NNI dynamics were monitored in the North of France. Monitoring was made both on field with destructive measurements and with a leaf-clip sensor (Dualex, Force A, Orsay, France), but also with a six-lens modular multispectral camera (Kernel camera, Mapir, San Diego, USA) embedded on an UAV.

Firstly, the Dualex, through the NBI measurement (Chlorophylls/Flavonols ratio), presents a relevant application to predict NNI as the relation between NNI and NBI was good (R^2=0.78) and stable between years and varieties. Secondly, with the multispectral modular camera which was able to take images in 15 different wavelengths (from 405nm to 940nm), eight vegetation indices (VI) were calculated giving 248 different wavelength combinations. These 248 combinations were, then, evaluated to assess their predictive capacity for crop NNI determination. Because it was difficult to identify a consistent and robust wavelength combination to monitor NNI, partial least squares (PLS) regressions were built and evaluated to consider more explanatory variables than simple VI which combine only few wavelengths' measurements.

Finally, non-parametric models offer the opportunity to combine the benefits of proximal and remote sensing. This study confirms the interest of this combination, which allows to take advantages of these two measurement scales: proximal sensing accuracy and spatial heterogeneity consideration by remote sensing. A NNI monitoring model combining remote and proximal sensing measurements was therefore built from 2020 and 2021 dataset. These models were subsequently tested in a farmer's plot in 2022. The results from this study could be applied for dynamic N fertilization management. From such method, it would be possible for farmer to apply the right fertilization according to real-time crop needs.

Effect of split N-fertilization timing on yield and quality in oat cultivars

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Summary

Using split N applications in oat enables a later decision for application rate, which could improve the precision to reach economic optimum. The objectives with this study was to 1) investigate how late the top dressing can be applied without negative effects on yield and quality in different cultivars and 2) the possibilities to predict optimum N fertilization rate at these stages.

Nine experiments in total were conducted at three sites in three years in the west part of Sweden in 2020-2022. The experiments had four varieties and nine (2020) or ten (2021-2022) fertilizer treatments in four replicates. Five (2020) or six (2021-2022) fertilizer treatments with different nitrogen levels from 0 to 190 kg N/ha were used to plot yield response and calculate economic optimum for the different varieties. The 100 kg N/ha treatment applied at sowing was compared with splitting with 70 kg N/ha at sowing and adding 30 kg N/ha at GS32, 45 or 55 and the 130 kg N/ha treatment was compared with 70 kg N/ha at sowing and adding 60 kg N/ha at GS32. At one of the sites, the experiment was duplicated with half of the replicates irrigated. All plots were measured with the Yara N-sensor at GS 32 and 45.

The effect of the different N-strategies on yield and quality did not depend on cultivar. In 2020, the yield tended to decrease with later top dressing than at GS32, although only significantly when applied as late as in GS55. In 2021, yield was significantly lower with split application already with second application at GS32, but differences were small and was not significant for GS45. Under the dryer conditions of 2021 the safer choice would have been one N-application at sowing. Both years, protein content was significantly higher with all split applications and with a tendency for higher protein with later second applications. Consequently, the second application can be performed at GS32, 45 or 55 and a similar yield, protein and N-yield can be obtained, but an earlier application is safer to obtain high yield. The results from 2021 indicate that good predictions of optimal N rates can be made from N-sensor measurements in zero fertilized plots combined with yield estimates both in GS32 (r^2=0.7) and GS45 (r^2=0.8). In the drier year 2020, the predictions were not as good.

Animal and crop producer involvement in N abatement: an example from the United States

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Nitrogen emissions and subsequent atmospheric deposition have contributed to ecological change in high elevation ecosystems of Rocky Mountain National Park (RMNP), an area protected from the effects of air pollution by law. Since 2000, the composition of wet N deposition was evenly split between NO_3 and NH_4 and since 2013, NH_4 has been slightly higher than NO_3. Much, but not all, of the NH_4 has an agricultural source; dairies, industrial animal feedlots, and irrigated corn and soy are important components of the regional economy. In 2007, the RMNP Nitrogen Deposition Reduction Plan agreed upon by the State of Colorado, the Environmental Protection Agency, and the National Park Service set a goal of reducing wet N deposition at the park by approximately 50% by 2032. An agricultural subcommittee formed to explore and implement voluntary options to discuss issues, track progress and facilitate actions centered around research, outreach, and incentives to reduce the emissions of NH_3 from agricultural operations. This committee has met quarterly since 2007 with state and federal agencies and researchers to share knowledge, address concerns, and discuss progress toward meeting the 50% reduction goal. Members of the committee also contribute research funding.

An automated early warning system was developed using the Weather Research and Forecasting (WRF) model to predict upslope mountain weather events when air that has been in close contact with agricultural operations will be transported to RMNP during periods of precipitation (Piña et al. 2019). Participants from the Corn Growers and Livestock Associations and others elect to receive notifications via text or email of impending weather events. These producers minimize activities related to livestock waste and/or fertilizer use during the warning period. A set of best management practices was developed to guide producers specifically during upslope events. Best management practices for year-round strategies related to feed management, animal housing, manure management, and crop nutrient management have also been approved by the committee.

Surveys, research, and continued efforts over more than 15 years to build a community around the shared goal of protecting National Park resources attest to the potential for voluntary collaborative efforts. A Guiding Principles document produced in 2021 confirmed the commitment to evaluate, validate, optimize, and adopt science-guided best management practices to reduce NH_3 emissions. Importantly, the committee pledged to encourage other stakeholders beyond the initial group to join in efforts to reduce emissions. We view the continued commitment of Colorado's agricultural community to work toward shared goals of protecting national park resources as a great achievement, even though atmospheric N deposition has not yet decreased.

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Optimising Nitrogen Use Efficiency on Grasslands

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Optimising the nitrogen use efficiency (NUE) dose on grasslands is key to boost the sustainability in dairy husbandry, in particular regarding the N losses to air and water. Recent studies showed that the recommended nitrogen (N) fertilizer rate can deviate more than 60 kg ha^{-1} yr^{-1} from the optimum given spatial and temporal variability in the nitrogen supplying capacity of the soil. Historic N fertilizer trials have shown a rather linear NUE response over a broad range of N doses (Ros & van Eekeren, 2016), but how the NUE response is controlled by site conditions such as soil properties (clay, organic matter, pH, water depth), weather data (precipitation, temperature, runoff events) and fertilizer strategy (right type, right dose, right time and right location) is largely unknown (Pijlman et al., 2020). Knowing that these site properties can change the NUE on field level, numerous historical and recent grassland field trial data were collected to unravel the relationships among NUE, N dose and the impact of these site conditions. Since 1950, over 250 trials have been carried out on 140 different locations across the Netherlands (n = 5.224 annual experiments), resulting in a database with about 10,000 grassland cuts. The main soil types were sand (46%), clay (21%), river clay (4%) and peat (28%). There was substantial variation in the capacity of soils to supply N, where the N supply was highly controlled by the soil organic matter level, the clay content and the number of degree days. The NUE was relatively constant over N doses ranging between 0 and 350 kg N ha^{-1} yr^{-1}, although the NUE varied considerably between sites and years. Using machine learning algorithms we unravelled the underlying mechanisms, with groundwater depth, fertilizer type, duration of the cut and the temperature degree days as main controlling factors. When tested on independent datasets, the NUE could be predicted satisfactorily ($R^2 > 0.76$) as function of soil properties, weather conditions and management options. For practical implementation in fertiliser recommendation systems, we distinguished five possible soil classes with different N fertiliser recoveries, and we additionally designed a forecast plume function to illustrate how the N uptake, the dry matter yield production and the NUE will change as a function of weather conditions and fertilizer inputs. Validating the model results on all recent trials showed that the NUE was predicted correctly in most of the cases allowing farmers to allocate their N fertilizer on their fields to increase the NUE on both field and farm level.

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Potential role of plant diversity in optimising nitrogen cycling in a Mediterranean grassland

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At the soil-plant system scale, all nitrogen (N) not exported at harvest is susceptible to undesirable losses such as nitrate leaching to water bodies, nitrous oxide (N_2O) emission, or ammonia (NH_3) volatilisation. In this context, plant sown diversity emerges as a promising tool for improving nitrogen use efficiency since mixed swards can affect both inputs (i.e., N fixation and transfer in mixtures including leguminous species) and outputs of N (e.g., enhanced exported N at harvest, reduction in greenhouse gas emissions).

With the aim to disentangle diversity effects on N cycling we set up an experiment following a simplex design (Kirwan et al., 2009) in a semi-arid agricultural area in Catalonia. The relative sown proportions of 3 forage species -a grass (*Festuca arundinacea* Schreb.), a legume (*Medicago sativa* L.), and a non-legume forb (*Cichorium intybus* L.)- were varied to provide a gradient in species proportions and evenness. Additionally, in the last experimental year (2011), two levels of N fertilization were tested. From 2008 to 2010 we measured $\delta^{15}N$ (as a proxy of N fixation), N content and export in harvest, and biomass production (also sampled in 2011). These data were complemented with inorganic N content in soil, and N_2O and NH_3 emissions (monitored in 2011 by Ribas et al., 2015).

As a general rule, mixed swards had a more efficient N cycling. The interaction between legumes and non-legumes increased the N content and export at harvest when compared to the average of monocultures. This could be partly due to enhanced N fixation and N transfer among species, but also to reduced losses (less N_2O and NH_3 emissions observed in the last experimental year). Remarkably, N fertilisation caused a drop in N fixation and N transfer from legumes, whereby non-legumes utilised more N from N fertilisation than from N transfer. All things considered, mixed swards merit attention as a valuable N management strategy which can potentially substitute fertilisation effects.

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Tropospheric ozone and atmospheric nitrogen deposition effects on nitrogen cycling in Mediterranean annual pastures

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Annual Mediterranean pastures are widely distributed in the Mediterranean area of Europe, constituting an important and species rich component of Mediterranean ecosystems. These pastures are chronically exposed to high air pollution levels, particularly tropospheric ozone (O_3) and atmospheric nitrogen (N) deposition. Ozone levels within the distribution area of Mediterranean annual pastures exceed current European air quality regulations for the protection of vegetation and in some areas atmospheric N deposition is above the critical loads established for the protection of European grassland habitats. Indeed, previous research has shown that several annual Mediterranean pasture species are sensitive to O_3 or N, but less is known about their interactive effects on the nitrogen cycle in these plant communities.

In order to study how O_3 and N deposition in combination can modify the N cycle, an O_3 fumigation and N fertilization experiment was performed using an experimental Mediterranean annual pasture community of 6 species growing in open-top chambers. Plants were exposed to 4 increasing O_3 concentrations from below ambient through to ambient and above ambient (+20 and +40ppb) and received 3 levels of N fertilization (none, 20, 40 kg N ha^{-1}) with double labelled (^{15}N) ammonium nitrate.

The experimental treatments showed an interactive effect between O_3 and N deposition on the N cycling, resulting in reductions of the fertilization effect of N deposition, effects on N pools and changes in input and output N fluxes in the plant community, such as reductions in the biological N fixation of some species and increases in N soil emissions (Sánchez-Martín et al. 2017).

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Riparian buffer strips influence N-losses as nitrous oxide and leached N from upslope permanent pasture: evidence from a field experiment and a meta-analysis

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Riparian buffer strips can significantly reduce nitrogen (N) transfers from agricultural land to freshwater primarily via denitrification and plant uptake processes, but an unintended trade-off can be elevated nitrous oxide (N_2O) emissions. Against this context, our replicated bounded plot scale study investigated N_2O emissions from N-fertilized un-grazed ryegrass pasture served by three types of un-fertilized riparian buffer strips with different vegetation, comprising: (i) grass riparian buffer with novel deep-rooting species; (ii) willow (young trees at establishment phase) riparian buffer, and; (iii) deciduous woodland (also young trees at establishment phase) riparian buffer. The experimental control was ryegrass pasture with no buffer strip. N_2O emissions were measured at the same time as total oxidized N in run-off and soil and environmental characteristics in the riparian buffer strips and upslope pasture over the period 2018-2019. During most of the sampling days, the no-buffer control treatment had significantly (*$P<0.05$*) higher N_2O fluxes and cumulative N_2O emissions compared to the remainder of the treatments. Our results also showed that the grass riparian buffer strip was a sink for N_2O equivalent to -2310.2 g N_2O-N ha^{-1} day^{-1} (95% confidence interval: -535.5-492 g N_2O-N ha^{-1} day^{-1}). Event-based water quality results (12 November 2018 and 11 February 2019) showed that the willow riparian buffer treatment had the highest flow-weighted mean N concentrations (N-FWMC) of 0.041 ± 0.022 and 0.031 ± 0.015 mg N L^{-1}, when compared to the other treatments. Therefore our 9-month experiment shows that riparian buffer strips with novel deep-rooting grass are potentially the best option for addressing N emissions to both water and air, at least in the short timeframe represented by our work. Existing international literature does suggest, however, that riparian buffers can also be sources of N_2O emissions. This suggests that careful selection of riparian buffer vegetation may be helpful since they can potentially emit more N_2O than the productive land they serve, especially over longer-term timeframes. In cases where managed agricultural land does emit more N_2O than riparian buffers, it is imperative to develop targeted mitigation measures.

Nitrogen use efficiency by pasture after sewage sludge addition in the region of Galicia (NW Spain)

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A new Circular Economy Action Plan for a Cleaner and More Competitive Europe has been recently released (March 2020) and again presents strong measurements to lead global efforts on circular economy and boost the efficient use of resources. An increase in secondary wastes such as sludges derived from water treatment operations is also observed due to the progressive implementation of the Urban Wastewater Treatment Directive 91/271/EEC in all Member States. Several studies proved that aerobically digested sewage sludge could be effective sources of N, P and K for crop production. The objective of this study was to evaluate the use mineral fertilisers (NPK) and different sewage sludge doses (SS40, SS80 and SS120 kg assimilable N ha^{-1}) combined or not with inorganic fertilisers (N and K) on (i) pasture production and (ii) efficiency in N use -calculated by agronomic efficiency and N use efficiency (NUE)-

Results indicated that treated municipal sewage sludge can be used as fertilisers for improving pasture production. The application of sewage sludge had a more positive effect in biomass production and efficiency in N use than application of mineral fertilizer. In general, no clear positive effects in pasture production when increasing the dose of SS addition from 80 to 120 were observed. Moreover, in several cases, a decrease in the efficiency of N use was observed when increasing the sludge doses, which indicates that the production of biomass is not lineal with the addition of N.

As expected, the results of grass N offtake showed that not all N added was used by the plant, in the case of the highest doses of SS (SS120), these treatments were always located in the risk area of inefficient N use (NUE < 50%), while in the case of intermediate (SS80) and low (SS40) doses of SS, NUE behavior changed with time: the first years of experiment the intermediate dose of SS (SS80) led to the best results in terms of N use efficiency, but this change during the last years and was replaced by the lowest dose of SS. In both cases, the presence of mineral fertiliser in the treatments did not affect N use efficiency.

It is important to highlight that the decrease of N use efficiency at high addition rates of sewage sludge may imply that sewage sludge behaves as a potential source of N.

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Nitrogen but not phosphorus addition affects symbiotic N_2 fixation by legumes in natural and semi-natural grasslands located on four continents

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The amount of nitrogen (N) derived from symbiotic N_2 fixation by legumes in grasslands might be affected by anthropogenic N and phosphorus (P) inputs, but the underlying mechanisms are not known. We evaluated symbiotic N_2 fixation in 17 natural and semi-natural grasslands on four continents that are subjected to the same full-factorial N and P addition experiment, using the ^{15}N natural abundance method.

Nitrogen, as well as combined N and P (NP) addition, reduced aboveground legume biomass by 65% and 45%, respectively, compared to the control, whereas P addition had no significant impact. Addition of N and/or P had no significant effect on the symbiotic N_2 fixation per unit legume biomass. Consequently, the amount of N fixed annually per grassland area was less than half in the N addition treatments (1.39 and 2.13 kg N ha^{-1} yr^{-1} in N and NP, respectively) compared to control and P addition (3.50 and 3.71 kg N ha^{-1} yr^{-1}, respectively), irrespective of whether the dominant legumes were annuals or perennials. Our results reveal that N addition mainly impacts symbiotic N_2 fixation via reduced biomass of legumes rather than changes in N_2 fixation per unit legume biomass.

The results show that soil N enrichment by anthropogenic activities significantly reduces N_2 fixation in grasslands, and these effects cannot be reversed by additional P amendment. This reduction in symbiotic N_2 fixation per area increases the dependence of grassland productivity on fertilization and can ultimately change the ecological functioning of grasslands, affecting their net primary productivity as well as their above and belowground biodiversity, forage quality and provision of ecosystem services.

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In search for the missing nitrogen in lowland agricultural basins: soils and canal networks as denitrification hotspots

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Denitrification is a key process buffering the environmental impacts of nitrogen excess in agricultural landscapes but, at present, remains the least understood and poorly quantified sink in nitrogen budgets at the watershed scale. The present work deals with a comprehensive investigation of nitrogen sources and sinks in agricultural soils and waters in a recently reclaimed and intensively cultivated coastal lowland, the Burana-Volano-Navigabile basin, in the Po River delta (Northern Italy), deeply studied in the last two decades and taken as a model.

Agricultural statistics, water quality monitoring, and results of laboratory experiments targeting N fluxes and pools in soils and waters were combined to set up a detailed nitrogen budget along the terrestrial–freshwater continuum and provide reliable estimates of denitrification at the basin scale.

Nitrogen inputs in soils exceeded outputs but this condition of potential surplus did not translate into widespread nitrate pollution. The general scarcity of mineral nitrogen forms in shallow aquifers, surface waters, and soils demonstrated a limited N runoff and storage. The high metabolic capacity of the Burana-Volano-Navigabile basin was ascribed to the combined effect of fine-textured soils with very low hydraulic conductivity and a capillary network of artificial canals and ditches. Soils in waterlogged conditions and consequent oxygen scarcity offer favorable environments for denitrification to occur. Furthermore, in the capillary network of artificial canals the multiple interfaces boost denitrification. Both features constitute an efficient buffer for nitrogen excess exerting a paramount ecosystem function and controlling eutrophication in the nearby coastal lagoons.

Results are discussed in view of the risk of soil mineralization, organic matter loss and consequent progressive loss of denitrification capacity in fine-textured soils. The importance of the adoption of conservative management practices for aquatic vegetation in the canal network, aimed at further increasing the watershed denitrification potential, is also discussed. Simulated scenarios suggest that restoration of aquatic vegetation may be an effective low-cost tool to mitigate the widespread nitrate contamination in surface waters, with potentially improved water quality at the basin scale and in the coastal zones.

Nitrogen fluxes and use efficiency in cropland and grazing systems in the Upper Paraguay Basin, Pantanal, Brazil

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The Brazilian Pantanal consists of one of the largest wetlands on the planet, encompassing a diversity of ecosystems and biodiversity. These natural environments, however, have been increasingly threatened by the expansion of anthropic activities in the highest areas of its drainage basin (Upper Paraguay Basin, UPB). The replacement of natural vegetation for expansion and intensification of agriculture has been linked to the loss of biodiversity and the provision of important environmental services.

In this study, we quantified nitrogen indicators for agricultural and grazing systems in 14 sub-basins in the UPB, considering the period from 2001 to 2017. The N indicators were used to investigate further the interplay between land use and land cover change, agriculture expansion and the N fluxes. The data were selected from local information, national databases, and the literature and consisted of nitrogen inputs (atmospheric deposition, biological fixation, organic manure, and synthetic fertilizers), outputs (harvested products and meat and milk production from cattle), and potential losses (soil erosion, leaching, and gaseous emissions). The data were compiled using a geographic information system to perform a spatial and temporal nitrogen budget considering a systemic approach. In addition, estimated nitrogen inputs and outputs in agriculture were used to calculate the nitrogen use efficiency (outputs/inputs; NUE).

Annual soybean and maize crops primarily represent cropping systems in the UPB, increasingly in rotation systems, and sugarcane and cotton to a lesser extent. The cropping system productivity has grown considerably, a fact mainly associated with the increase in fertilizer use and improvements in cultivation techniques. Nitrogen inputs grew by around 40% during the period, while N outputs have increased by about 20%. Soil erosion is a worrying issue that inappropriate agricultural practices have aggravated. Associated with other pathways in cultivated systems, it was estimated an increase of about 60% in N losses. The results indicate annual deficits of N in agriculture systems a susceptibility of productive soils to degradation.

N fluxes in grazing systems are considerably lower, due to the characteristic production systems of the region, in which the cattle are raised free in extensive pasturelands. The creation of these animals in natural pastures is the typical system for Pantanal, but it has been gradually replaced by exotic pastures and the supplementation with feed is an expected trend in the region. Gains in milk and meat production increased N outputs in the period, estimated at around 70%. Results point to N accumulation, indicating that there may be a limitation of other nutrients and the possibility of better use of the nutrient from adjustments in production practices.

Comparing global regions using Pressure-State-Impact metrics of nitrogen threats

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Multiple factors influence how excess reactive nitrogen (Nr) – that unintentionally released through combustion or agriculture – influences the environment and human health. Regional comparisons of threats from excess Nr can help motivate stakeholders and target management actions. We developed a list of priority indicators of nitrogen impacts following the Driver-Pressure-State-Impact-Response model (DPSIR), focusing on N Pressures, States and Impacts for water quality, air quality, greenhouse gas emissions, and ecosystem biodiversity. We then compared seven global regions that differ in nitrogen accessibility and socio-economic status, using publicly available data, either recently published or available through agencies. We assessed the extent to which national or regional regulatory standards matched those of international agencies (WHO, UNEP), and how that match related to indicator status in the different regions. Finally, we identified regional data gaps for several key metrics of nitrogen impacts.

Recent national, regional and international assessments suggest increasing impacts from Nr to water quality, air quality, GHG emissions and biodiversity. However, trends across regions vary greatly, and depend on the metrics assessed. Most national standards addressed ecosystem state (e.g., concentrations of particulate matter or ozone for air quality, concentrations of nitrate in drinking water). High income countries in multiple regions that saw the greatest impacts on water and air quality in the late 20th century also typically had earliest implementation of regulations to reduce N emissions and those impacts. This has been most dramatic for air quality. In contrast, rapid development and population growth without infrastructure and regulatory standards to match have led to the most rapid growth of Nr impacts in developing countries. Few standards exist for nonpoint release of Nr from agriculture, which can predominate in many regions and Nr impacts (e.g., NH_3 for air quality, leaching for water quality). Management efforts to address these impacts may take a relatively long time to achieve water quality goals, due to nutrient storage and complex ecological interactions mediating responses. Identification of causal ecological mechanisms linking Nr to some phenomena (e.g., harmful algal blooms) remains elusive due to those same complex ecological drivers. The development of monitoring networks and consistent global databases are increasing scientific ability for such regional comparisons. However, detailed coverage is still lacking in many regions, such as Africa and Latin America, even for impacts that directly affect human health and ecosystem benefits, such as air and water quality.

Carbon-Nitrogen coupling in arable cropland soils: data at the plot scale in the central Paris basin.

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The observed relationship between N surplus (difference between total N soil inputs and N output through harvest integrated over the whole crop rotation cycle) and N losses (through denitrification and leaching) in arable cropland is often blurred by the complex dynamics of soil organic matter, which can results in either release of mineral N or sequestration of N in the organic matter pool.

We collected a large data set of N and C flows and stocks measurements in 64 plots of 17 commercial farm plots in the central Seine basin (France) for which detailed farming practices and production figures were recorded through interviews. These plots belong to a network of farms (called ABAC), which was followed from 2011 to 2019, and include both conventional and organic systems (Benoit et al., 2016; unpublished).

The AMG model (Clivot et al., 2019), slightly modified to deal with dissolved organic carbon leaching (Garnier et al., 2022), was used to determine the position of the currently observed organic carbon pool (OC) with respect to the steady state value corresponding to the current farming practices (OCeq). Those plots with OC higher than OCeq were expected to release organic carbon, hence mineral N, while OC was expected to be sequestered, and mineral N released, in the opposite case.

These data were confronted with the measurements of N losses from the same plots: N leaching was estimated with suction cups and N_2O emission, hence denitrification, with empirical relationships. A full N budget at the plot scale could therefore be established, showing the respective influence of all loss and storage processes.

This work offers a solid basis to discuss the importance of soil organic carbon dynamics on the N flows from arable cropland and reveals that organic farming practices keep leaching at constant low values up to surpluses circa 80 kgN/ha/year. Contrarily to conventional farming before the 2000's, which showed a linear leaching in function of surplus, a great variability is obtained for recent period, with a diversification of practices that do not seem to have stabilized.

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INCREASING TROPOSPHERIC OZONE IMPACTS WHEAT NITROGEN USE EFFICIENCY

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Tropospheric ozone (O_3) is a secondary air pollutant that has been increasing since the industrial revolution due to the anthropogenic emissions of its precursors (NOx, VOCs, CO) into the atmosphere. Its high oxidant capacity affects plant metabolism and physiology (e.g., reduces stomatal conductance and photosynthetic rates, and leads plant resources towards antioxidant activity losing yield capacity). Ultimately, the pollutant accelerates plant senescence and reduces yield. Wheat has been found to be the most O_3-sensitive among the stable crops, making the pollutant one of the most hazardous problems related to Global Change for agriculture in the northern hemisphere.

In the present work we try to understand, through different assays, how O_3 affects different pathways of nitrogen (N) use within the plant from uptake, assimilation and remobilization through the response of parameters like photosynthetic N Use Efficiency (PNUE), Grain N Yield (Total N Output, TNO), Nitrogen Remobilization Efficiency (NRE), Nitrogen Harvest Index (NHI) and N use efficiency (NUE).

Results presented are based on three wheat assays performed in independent years carried out under seminatural experimental conditions in the CIEMAT Open Top Chamber (OTC) facility located in central Iberian Peninsula: Assay 1- to analyse the homogeneity of the O_3 response of different Mediterranean wheat genotypes, from landraces to modern cultivars. Twelve genotypes were analysed for this screening; Assay 2- to analyse the modulation of the wheat O3 response by N fertilization. The O_3-sensitive cultivar Arthur Nick was considered. Two N-fertilization treatments were considered of 100 and 200 kg N ha^{-1}; Assay 3- to analyse the wheat O_3-response by the water availability. The O_3-sensitive cultivar Califa Sur was used. Two irrigation treatments were considered: full irrigation until field capacity and supplemental irrigation which meant 45% less total water input (irrigation plus rain).

For all the assays plants were exposed to 4 O_3 treatments: charcoal-filtered air (FA), non-filtered air (NFA), NFA+20 ppb (NFA+) and NFA+40 ppb (NFA++). In assays 1 and 2, O_3 fumigation started at anthesis; in Assay 3 it started at the early vegetative stage.

All three assays significantly highlighted the ability of O_3 to disrupt N-processes within the plant, affecting N use efficiency, specially the modern and O_3-sensitive genotypes. Nitrogen and water availability modulate the response to O_3 exposure.

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Monitoring atmospheric deposition of nitrogen at the landscape level in Germany from 2005 till 2020

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Mosses are particularly suitable for recording the accumulation of atmospheric substance inputs over large areas at relatively many sites. In Europe, this has been done every five years since 1990 in the European Moss Survey. Mosses have been collected at up to 7312 sites in up to 34 countries and chemically analysed for heavy metals (since 1990), nitrogen (N, since 2005) and persistent organic pollutants (since 2010). In Germany, in addition to the measurement data from the chemical analysis, data were collected for each moss collection site on site and environmental characteristics that could have an influence on the accumulation of atmospheric deposition in mosses. These potential predictors were included in the statistical analyses so that their significance could be determined. The measured values for N, which are well above the quantification limit, are reliable. The minimum number of samples required to estimate the arithmetic mean with a 20% margin of error was achieved. Inferential statistics results confirm significantly higher N enrichment in moss samples collected under tree canopies compared to adjacent open land. Trends in state-wide N medians over the last three campaigns, 2005 to 2020, show that N medians (2005: 1.46%, 2015: 1.43%, 2020: 1.54%) decrease by -2% between 2005 and 2015, increase by +8% between 2015 and 2020, and increase by +5% between 2005 and 2020. The differences are all non-significant (α=0.05) and are not consistent with the following emission trends: Between 2005 and 2019, decreases in NOx emissions of -31% and NH3 emissions of -3% were observed in Germany. While NOx emissions have been continuously decreasing since 2005, NH4 shows an increase since 2005, but a decrease of -15 % since 2015. While the decreases in N emissions since 2005, and thus also in N levels in mosses, are mainly due to the declining use of fuels in various sectors, agriculture, which was responsible for about 95% of total NH3 emissions in 2019, remains an important driver for the overall high atmospheric N deposition since 2005 and thus for the correspondingly high N enrichment in mosses.

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Assessment of different N treatments in Hedgerow Almond Orchards by means of LiDAR point clouds

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Monitoring of canopy status in fruit tree orchards allows better decisions in the canopy management, such as pruning or fertirrigation. LiDAR is an effective tool to acquire accurate 3D geometric and structural data, such as height, width, volume or canopy porosity, among others. In the present work, a super-intensive almond orchard (*Prunus Dulcis*) with 8 different N treatments (N50, N100, N150, NStop: N100 only in Fase I and with and without DMPSA nitrification inhibitor in 24 rows and 3 blocks, was scanned during three years (2019-21) in two different vegetative stages (after spring pruning and before harvesting) by means of a terrestrial LiDAR scanner. Canopy parameters such maximum height and width, cross section and porosity were summarized from the LiDAR 3D point cloud every 0.5 m along the almond tree hedgerows. A repeated measure mixed statistical model was applied to each parameter in order to assess the effect of the N treatments. The adjusted R^2 ranged from 0.73 of the canopy width to 0.83 of the porosity. Canopy parameters and their main interactions with the different treatments were significantly differentiated. The N100+DMPSA treatment was the one favoring higher canopy development (higher cross sections and widths, and less porosity), while the NStop+DMPSA treatment was related to lower canopy development and higher porosity.

Accurate assessment of grass nitrogen status based on multispectral data from two optical sensors and the critical nitrogen dilution curve

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The critical nitrogen dilution curve (CNDC) is efficient for diagnosing plant nitrogen (N) deficiency. For perennial plants, including grasses (family *Poaceae*), deriving CNDC is not straightforward due to in-season modulations by cuts and fertilization. Gislum et al. (2009) developed CNDC for grass species for seed production in Denmark and suggested improvements since it was not possible to calculate a % critical N concentration at biomass lower than 2 Mg ha^{-1}. Optical sensors deployed on the field can partly answer the question of how much and when to fertilize, e.g., the Yara's N tester (Yara International ASA, Oslo, Norway) that allows assessing plant N requirement and real-time variable-rate spread of fertilizer. Moreover, multispectral data from unmanned aerial vehicle (UAV) with their ultra-high spatial and temporal resolution can also be used to estimate crop N status (Peng et al., 2021), though high accuracy is difficult to achieve due to the dynamics and the transformation of N. Accurate N management requires establishment of a solid 'link' between the remote sensing data and the crop N status. Parametric regression involving models of linear or nonlinear nature has often been used for describing this link (Peng et al., 2021). Peng et al. (2021) investigated how well potato N status can be described by RS data obtained from ground, air- and spaceborne sensors using parametric and non-parametric, i.e., machine learning regression. Few previous studies have used RS to calculate the N status of grasses and predict their N requirements. The objective of this study is to estimate precisely the amount of N fertilizer needed for optimal plant growth according to N requirement and the CNDC by two optical sensors (Yara N sensor and UAV-mounted) based on machine learning method (random forest and alike). Two-year field experiment has been initiated with grass (*Lolium perenne*) in 2022 and 2023 (established in September 2021) on a sandy loam soil in Denmark, with four nitrogen rates (N0: 0 kg ha^{-1}, N1: 75 kg ha^{-1}, N2: 300 kg ha^{-1} and N3: 450 kg ha^{-1}). We present initial results of the canopy multispectral reflectance and CNDC developed for the grass and provide novel insight for improving N diagnosis and management of grass in Denmark and Europe.

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Analysing the optical response of nitrogen and phosphorous addition on a semiarid grassland using hyperspectral field spectroscopy and airborne data

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Iberian dehesas and montados are managed open oak woodlands with native grasses as understory, that provide ecosystem services for these territories (more than 3,5 million ha). A growing number of short-term N-enrichment experiments have shown that semi-arid grasslands are extremely sensitive to increases in available N inputs which can produce alterations in plant community composition and primary production (Chen et al., 2018, El Madany et al. 2021).

To assess the effect of climate, nutrient availability and management a large-scale fertilization (20 ha) with nitrogen (N) and nitrogen plus phosphorous (NP) experiment (Max Plank Institute for Biogeochemistry, Jena, Germany) was established in a dehesa ecosystem with a 20% *Quercus ilex* coverage located in Majadas de Tiétar (Cáceres, Spain). Carbon and water fluxes are continuously monitored by eddy covariance methods and hyperspectral optical data are frequently acquired using field spectro-radiometers and airborne sensors.

This study analyzes the effect of the N and NP fertilization on the optical response of the native multispecies grass layer using hyperespectral data acquired at the plot level (25 * 25 m) using a ASD Fieldspec 3 spectroradiometer (400 to 2500 nm) and at ecosystem level using Compact Airborne Spectrographic Imager (CASI) and Airborne Hyperspectral Scanner (AHS) images acquired in 5 campaigns during the pre- and post-fertilization periods (2014-2017). Results show significant differences in vegetation indices in spring along all regions of the optical domain for the N and NP treated areas in the post-fertilization period studied at both plot and ecosystem level.

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Hyperspectral and thermal sensors for distinguishing between nitrogen and water stress in winter wheat

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Remote sensing (RS) is a valuable tool to determine crop nitrogen (N) and water status. However, it can be difficult to identify the stress suffered by the crop due to confounding effects. This study evaluated the potential of RS indicators to assess N and water status without confounding effects (Pancorbo et al., 2021). A field experiment with winter wheat was established in Spain during 2018 and 2019. In the trial site, 32 plots were split into four N levels at the beginning of the stem alongation, and two water levels at flowering. The N status was determined at three growth stages with onground measurements of Nitrogen Nutrition Index (NNI). Water status was measured with a leaf porometer at flowering 2019. Canopy reflectance was measured with a hand-held FieldSpec spectroradiometer (400-1000 nm), and with an airborne hyperspectral sensor (400-1750 nm) the same dates as NNI determination. An airborne thermal sensor was also used to map the experiment at flowering.

The planar domain Canopy Chlorophyll Content Index (CCCI) showed the most robust correlation with NNI in all growth stages ($R^2 > 0.44$) with both sensors, even at the earliest growth stage, when other indices did not correlate with NNI but CCCI compensated for the background noise. The CCCI identified the N levels with minimum effect of the water levels. The thermal indicator Water Deficit Index (WDI) obtained the highest correlation with the leaf porometer ($R^2 = 0.66$), and indentified the two water levels without effect of the N status.

This study concludes that spectral and thermal information can be used to assess N and water status without confounding effects, and therefore, to adjust N fertilization and irrigation.

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Wheat grain protein content estimated by machine learning from hyperspectral and thermal remote sensing images

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Wheat (*Triticum* spp.) grain protein content (GPC, %) is crucial to farm incomes and is strongly influenced by crops' physiological status, stress, and agronomic practices. Accurate GPC estimation from remotely sensed plant traits has potential to reduce N losses and improve farm profits but has seen limited success. To advance, it is necessary to identify the imaging spectroscopy-based plant traits most closely associated with GPC. We flew hyperspectral missions at two dryland plot experiments with a broad range of N treatments and contrasting water supply, and 17 commercial bread or durum wheat fields, over two climatically divergent years in the southern Australian wheat belt. We captured images with airborne hyperspectral and thermal sensors, at spatial resolutions of 0.3—0.5 m for the plots and 1—1.7 m in the crops. Leaf-level spectroscopic measurements, leaf and grain samples were collected in the plots and for the crops we obtained ~40,000 GPC records from on-combine monitors. From thermal image rasters and hyperspectral data cubes, we retrieved Crop Water Stress Index (CWSI), solar-induced fluorescence (SIF), reflectance indices and PRO4SAIL radiative transfer model inverted parameters for each plot and GPC record. At both leaf and canopy scale, and in both plots and transect, we observed a consistent association between the photochemical reflectance index (PRI), related to xanthophyll pigments, and GPC. In the commercial crops, a machine learning algorithm ranked CWSI as contributing the most gain to GPC estimation under severe water stress, while in more benign conditions SIF and PRI were consistently important, as were anthocyanins and carotenoids retrieved by inversion. Structural traits were not prominent except in severe drought. The best relationship between predicted and observed GPC in unseen test samples was r2 = 0.80 in a model that included thermal and physiological traits.

Tree-based leaf N prediction and management zones as tools to optimize N application and minimize leaching

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Improper nitrogen (N) application is a global phenomenon that negatively affects farmers and the environment. Proper N application must follow the plant's needs, as expressed by an uptake curve and adjusted based on the plant's nutritional status. The latter is commonly done through tissue (leaves) sampling. However, field-scale spatiotemporal variability, sampling time and costs, and infrastructure limitations hinder the ability to provide each plant with its needs. This study aims to (1) predict leaf N content at the tree level in a commercial orange (*Citrus sinensis valencia*) orchard, taking into consideration spatial and temporal variation, (2) build dynamic management zones for N application, and (3) monitor and simulate N losses through leaching. For doing so, a four-year study was conducted in a commercial orange orchard on Israel's Coastal Plain. Every two months, leaves were sampled from 48 sampling trees in conjugation with multi-spectral areal imagery. A support vector machine (SVM) model was developed and predicted the leaf N content in each tree in the orchard, with R^2=0.77. A flexible clustering model was developed, enabling splitting the orchard into several Management zones (MZs) (Ohana-Levi et al., 2020). In addition, an envelope curve was generated for the October-November leaf N contents and yields. Optimal N contents were used to represent all the trees in an orchard as "under," "sufficient," or "over" fertilized. MZs based N application reduced the ratio between the maximal and minimal yields and the standard deviation (SD) between the yields per tree in the orchard. Porewater sampling and tensiometers were used to monitor and predict (Using the HYDRUS 1D model) the impact of tree size, soil profile, and water and N application on leaching. These were integrated as a site-specific N management system to improve fertilizers application in a citrus orchard.

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Optimal nitrogen management in rice and wheat based on normalized difference vegetation index using sufficiency index

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Surplus increase in N use than average grain yield in wheat and rice has continuously declined the nitrogen use efficiency (NUE) less than 0.35 and 0.26 kg yield of N per kg respectively in Pakistan (Shahzad et al. 2019). The opportunities exist in this valuable trait to increase its efficiency for balanced crop nutrition, use of fertilizers with increased efficiency and in-season precise N management. Experiments on wheat and rice were conducted for two growing seasons (2018-19) at N rates 80, 160, 200 and 240 kg ha^{-1} and 80, 120 and 160 kg ha^{-1} including no N as control respectively. Higher grain yield, total productive tillers, 1000-seed weight and biological yield of wheat were found at 200 kg Nha^{-1}. Maximum agronomic NUE (4.28) and recovery efficiency (18.48%) were also observed at similar N rate associated with high total N uptake (TNU) at anthesis. Positive relationship of TNU and grain yield was found with NDVI and chlorophyll contents during booting and heading stages. Higher seed yield at 200 kg N ha^{-1} was associated with delayed senescence predicted using normalized difference vegetation index (NDVI). In rice, application of 120 and 160 kg N ha^{-1} produced similar straw and seed yields including harvest index. Higher yields for these N rates was attributed to reduced spikelet sterility (24-29%), improved filled kernels (16.09-19.53%) and productive tillers (21.00-31.07%). Increasing N supply reduced agronomic AE and physiological efficiency (PE) while improved RE (30.81-58.57%). Strong association of NDVI with leaf N, TNU with sufficiency index (SI) and grain yield showed that rice crop achieve optimal N concentration during active tillering period to support growth. Higher benefit to cost ratio showed that 200 kg N ha^{-1} in wheat and 120 kg N ha^{-1} in wheat can be optimal to improve NUE and reduced detrimental losses to economize N use (Rehman et al. 2021). Similarly, SI can be good indicator to predict the N schedule during panicle initiation or heading stages to avoid yield limitation in both rice and wheat for sustainable crop production.

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Sensing Nitrogen dynamics in spatially and temporally diversified cropping systems

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Proximal and remote sensing technologies have been widely applied to study crop biophysical parameters and soil properties related to nitrogen (N) . However, tracking soil N is challenging due to its dynamic relationship with soil moisture, crop species and management, and its complex transformation processes taking place at different temporal and spatial scales. The objective of this research is to investigate the nature of relationship between sampled and measured plant N, soil N_{min} and in particular NO_{3-} with proximal sensed soil moisture and temperature data, and remotely sensed imagery (vegetation indices at different spatial scales), using heterogeneous data for ground truth.

The experiment was conducted over two cropping cycles in Tempelberg, Brandenburg, where a large 70 ha field was divided into 30 smaller fields of ~0.5 ha (72m x 72m) by considering the small-scale soil heterogeneity, defined as patches (Grahmann et al., 2021). Four patches cropped with rye, rapeseed, wheat, oat in 2021 and Barley, rapeseed, sunflower, maize in 2022 have been selected for soil and biomass data collection. Sampling was conducted in six location during 3 different vegetation stages and six sampling points along a transect from the center of each patch to the edge. Soil moisture and temperature were recorded at (10, 30, 60 and 90 cm depth) at a 20 minute interval in each patch. Remote sensing imagery from drone (every 2-4 weeks), Planet, and Sentinel-2 were collected in 3-5 days intervals to capture the phenological development. Different interpolation and data smoothing methods will be tested to increase the number of point data. Correlation and multivariate regression will be conducted to find suitable upscaling approaches among field samples, environmental variables and proximal-remote sensing datasets (Preza Fontes et al., 2019).

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Fine-tuning fertilization strategies to local production conditions through on-farm experimentation

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Improving nitrogen (N) use efficiency (NUE) is an agricultural essential for increasing crop productivity, while decreasing environmental degradation. However, decisions on fertilization management are usually taken by previous experiences or farmer's insights. Moving towards farm data-driven decision-making could significantly improve crop fertility management. Spatial variables such as soil type, topography or electrical conductivity and temporal variables such as weather, crop rotation or field management could contribute to explain crop response to different fertilization strategies. In the 2020-2021 growing season, 52 field trials were implemented at farm scale to evaluate different fertilization strategies in arable crops. Nitrogen rate was fixed according to crop N needs in each specific location, but time of application, fertilizer source and incorporation of nitrification inhibitor were tested. Preliminary results suggest high-effect of late winter precipitation and moderate yield response to the use of nitrification inhibitors. Current research is focused on increasing the experimental network over the next years to better understand temporal variability and site effects on crop yield and to provide farmers with local data for improving fertilization practices.

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Winter wheat traits prediction through ensemble modeling approaches using hyperspectral and Sentinel-2 imagery

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Estimation of in-season crop parameters from remote sensing (RS) indicators can be used to predict final crop traits, and to adjust nitrogen (N) and water rates. Despite the hyperspectral sensors offers more information than multispectral sensors, the freely available multispectral satellite images are receiving increasing attention due to their accurate measured reflectance and ability for crop monitoring (Pancorbo et al., 2021).

The present study analyzed whether the estimation of winter wheat yield, grain protein concentration (GPC), and N output improved by combining RS spectral indices related to different crop biophysical parameters at flowering. For this purpose, a field experiment planted with winter wheat combining four N and two water levels in 32 plots (22 x 22 m) was conducted in central Spain over 2 years; 2018 and 2019. Wheat traits were measured at harvest, reflectance from an airborne high-resolution hyperspectral sensor, and from Sentinel-2 (Level 2A) imagery were acquired at flowering both years. A parametric linear model using all hyperspectral normalized difference spectral indices (NDSI) and two non-parametric models (artificial neural network and random forest) were used to assess their estimation ability combining different NDSIs. The estimation ability was also analyzed when the NDSIs were calculated with Sentinel-2.

Yield estimation was the most accurate evaluated wheat trait, and obtained similar R^2 values when NDSIs were retrieved with the hyperspectral sensor or with multispectral Sentinel-2 bands ($R^2 \approx 0.84$). Accurate estimation of GPC was obtained with both sensors when the short-wave infrared (SWIR) region was included (R^2 = 0.73 and 0.69 with the hyperspectral and Sentinel-2, respectively). The red-edge and SWIR-based NDSIs were important for improving N output estimation with the hyperspectral sensor (R^2 = 0.74) and with Sentinel-2 (R^2 = 0.71).

In this study, the hyperspectral sensor and Sentinel-2 showed satisfactory results in wheat traits prediction, and the use of SWIR information was key to improve the assessment of N-related wheat traits.

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High-resolution airborne hyperspectral data for spring wheat assessment: yield, biomass, grain N concentration and N output

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Cereals respond to nitrogen (N) fertilizer applications by increasing yield and/or grain N concentration (GNC), so fertilization is a common practice among farmers throughout the world. Remote sensing allows fast and cost-effective assessment of crop monitoring over large areas. However, questions regarding specific strategies to predict crop parameters and improving N fertilization remain open. Therefore, the goal of this study was to optimize the use of remote sensing spectral information combined with agronomic data for its application to yield and grain quality assessment, and decision making on spring wheat fertilization. Spring wheat (*Triticum turgidum* L.) experiments were conducted in Northwest Mexico over 4 consecutive years (Raya-Sereno et al. 2021). Each year, a factorial design in blocks with two tillage treatments, two irrigation levels and six N treatments were combined. Airborne hyperspectral images were acquired with a micro-hyperspectral camera ranging from 400- to 850- nanometers through numerous flight campaigns from the beginning of stem elongation to medium milk. At harvest, grain yield (GY), biomass, GNC and N output were determined. Spectral exploratory analysis was applied to identify the best wavelength combinations, the most suitable vegetation indices (VIs), as well as the best growth stages to assess the agronomic variables. The relationship between the spectral information and the agronomic measurements was evaluated by the coefficient of determination (R^2) and the root mean square error (RMSE). The ability of the indices to manage fertilizer recommendation was considered through an error analysis based on the N sufficiency index. Grain yield was better assessed by VIs based on the combination of bands from NIR/visible and NIR/red-edge regions from the end of flowering to the early milk stage ($R^2 > 0.6$; RMSE < 700 kg ha^{-1}). N output was efficiently assessed by a combination of bands from NIR/red-edge at booting ($R^2 > 0.7$; RMSE < 9 kg N ha^{-1}). The GNC was better estimated by VIs combining bands in NIR/red-edge at early milk. Some VIs were promising for conducting fertilizer recommendations for increasing GNC; nevertheless, there was not a single index providing reliable recommendations every year. This study emphasizes the potential of remote sensing imagery to assess GY and N output in spring wheat. However, more research is required for identifying GNC response sites.

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High-resolution hyperspectral imagery and ground-level sensors to detect N fertilizer rate and residual effect in winter wheat

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The use of mineral fertilizers has increased in the last decades, but >50% of nitrogen (N) applied is not assimilated by crops, leading to environmental pollution. Monitoring crop performance could contribute to adjust N fertilization and increasing N recovery. Our main objective in this work was to evaluate the ability of ground-level sensors and high-resolution hyperspectral imagery for identifying N fertilizer rates and the residual N effect from the previous crop fertilization. A two-year field experiment with a maize-wheat crop rotation was established in Aranjuez (central Spain) (Raya-Sereno et al. 2022). Maize (*Zea mays* L.) was sown in sixteen plots (8 × 10.5 m) randomly distributed in four treatments with four replications. The treatments were: calcium ammonium nitrate enriched with sulphur (CAN), ammonium sulphate nitrate (ASN) blended with 3, 4-dimethylpyrazole phosphate (DMPP) (ASN+DMPP), CAN blended with 3,4-dimethylpyrazole succinic (DMPSA) (CAN+DMPSA) and non-fertilized. After maize harvest, wheat (*Triticum aestivum* L.) was sown and each plot was split into three subplots (3.5 × 8 m). Each subplot received CAN either at a recommended N rate (N2), a reduced rate (N1) or no N applied (N0). Ground-level sensors (Dualex® and Greenseeker®) readings and vegetation indices calculated with the reflectance acquired by two airborne hyperspectral sensors were compared with wheat parameters. In addition, biophysical and biochemical plant traits were retrieved by model inversion. Ground and aerial sensors differentiated wheat N rates at several growth stages, providing significant differences already at stem elongation. Residual N effect was observed in biomass and N content at flowering in N0 treatments, as the results were higher in the CAN+DMPSA and ASN+DMPP treatments compared to the control. Additionally, the structural (NDVI, OSAVI), chlorophyll (CCCI, NDRE), blue/green, NIR-SWIR ($N_{850,1510}$) vegetation indices, together with chlorophyll, biomass and LAI estimated by model inversion detected the residual effect at different growth stages. Therefore, this study proved the potential of ground and remote sensors to distinguish N rates at early growth stages and emphasized their ability to detect residual N in a crop rotation.

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Monitoring agricultural patterns in Central Valley, California during a multi-year drought with AVIRIS imagery

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During 2012-2016 California experienced the longest and most severe drought in the last 1200 years. The water scarcity led to an increase in non-cultivated croplands during this period. The objective of this study was to analyze the agricultural trends in Central Valley, California during the summers of the 2013-2018 time period. For this purpose, it was analyzed the yearly official harvested area reported at County level for each species, and the visible-shortwave infrared (VSWIR) spectra acquired by the Airborne Visible/Infrared Imaging-Spectrometer (AVIRIS) over 2334 km2 of the Central Valley each year. Multiple Endmember Spectral Mixture Analysis (MESMA) was applied in the AVIRIS images to quantify the fractions of green vegetation (GV), non-photosynthetic vegetation (NPV) and soil in the crop fields each year (Shivers et al., 2019). The agricultural patterns showed by MESMA results were compared to the harvested area obtained from the local crop reports.

MESMA and crop reports analyses indicated that non-cultivated areas increased during the drought; with the smallest GV in 2015. This year was the second with exceptional drought in the time period. According to MESMA, 34% of the croplands was covered by GV this year, and $172 \cdot 10^4$ ha according to the crop reports. MESMA also registered the highest value of bare soil area in 2015 (47%). The year with most area cultivated was 2017, with 54% of the area covered by GV and $183 \cdot 10^4$ ha. This study verified that the non-cultivated areas increased in Central Valley during the exceptional drought period, and validated the use of AVIRIS imagery to monitor cropland use changes in future climatic extreme events.

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Nitrogen status monitoring of sugar beet crop with ground and remote level sensors

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Strategically during the last recent years some sugar beet crop management tools have been developed, including crop nutritional status monitoring with a broad type of sensors. In this context and with the purpose of implementing those tools, a research project was carried out in Navarra (Spain) in 2020 by UPM with AZUCARERA, AIMCRA and HEMAV. One of the main goals of this project was to evaluate the ability of various ground (SPAD) and remote (multispectral camera on drone) sensors to characterize sugar beet nitrogen status along the crop cycle. A trial was carried out in Artajona (Navarra, Spain) in 2020, with three nitrogen doses (50, 140 and 210 kg N ha^{-1}) and four replications in plots of 10x6 m^2. The recommended dose (RD) of 140 kg N ha^{-1} was estimated using AIMCRA formula based in presowing soil organic matter. At six dates along the crop cycle, readings were taken with SPAD-502® in sugar beet plant (15 leaves per plot). Besides, drone images were acquired with a multispectral camera and various indexes were calculated: the structural index NDVI, the chlorophyll index NDRE and the combined index TCARI/OSAVI. Moreover, sugar beet plants were sampled, and nitrogen content and plant biomass were measured in those dates. Therefore, crop N status indexes were calculated using the critical NC curve of sugar beet crop: nitrogen nutrition index ($NNI=NC_{actual}/NC_{critical}$) and nitrogen concentration deficit ($NCD=NC_{critical} - NC_{actual}$). Sensor monitored indexes were significantly different between N application doses, for both ground level sensor measurements (SPAD) and remote level sensor in drone (NDVI, NDRE and TCARI/OSAVI). Moreover, plant N content indexes showed differences between N application treatments. Additionally, strong correlations were found between sensor derived indexes and plant N status indexes. Particularly, TCARI/OSAVI index showed consistent correlations with plant N status, and therefore this index can be useful in monitoring crop nitrogen status along crop cycle and then as a decision support tool in nitrogen fertilization management in precision agriculture.

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Developing a new tool for N optimization and precision agriculture in potato farm

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Several Decision Support Systems (DSS) have been developed to optimize nitrogen fertilizer inputs. Among all, those using remote sensing technologies have been further developed and applied in recent decades, especially for wheat crop, but little was done for other crops, such as potato. However, remote sensing techniques represent a way to characterize and analyse the interaction between nitrogen treatments, crop variety and underlying spatial variability at field-scale. The aim of this research was to develop a new tool for N optimization in potato farm, integrating remote sensing data.

Since 2016, several microplot (~50 trials) and on-farm experiments were set up (~30 trials) in France. The two objectives were to identify the characteristic traits of varieties for nitrogen use efficiency (NUE) with high-throughput phenotyping tools, and to improve NUE by nitrogen fertiliser application. The methodological hypothesis that these trials can help to answer is whether the vegetation indices measured during the cycle are correlated with agronomic variables. Conventional crop and soil measurements were compared with vegetation indices calculated from crop reflectance data. All these variables can be acquired with a temporal kinetics. This data was acquired using different vectors (satellite, ULA, ALPHI®) with a variety of mounted sensors (RGB or multispectral cameras) to provide information such as soil cover fraction and vegetation indices (NDVI, etc.).

The experimental networks on potatoes show the reliability of these technologies to fertilizer management evaluation. Statistically significant correlations have been found between agronomical variables and vegetation indices to develop reliable DSS, with more than 80% of validated model results, without yield loss. Moreover, trial results have allowed us to demonstrate a different way to phenotype the crop. In the long term, the results will therefore help to improve NUE in potato farm management.

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Food Waste Management towards Nitrogen Recovery

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Despite the economic and environmental costs, a substantial amount of food is wasted globally, indicating a failed food system. Food waste from households, retail establishments, and the food service industry totals 931 million tonnes each year. Nearly 570 million tonnes of this waste occurs at the household level. The global average of 74 kg per capita of food wasted each year is remarkably similar from lower-middle-income to high-income countries, suggesting that most countries have room for improvement in addressing the issue of food waste. On a per-capita basis, 121 kg of consumer-level food is wasted globally, which translates to around 17% of available food every year.

In view of the growing need to address the food waste crisis, there is an urgency to meet a zero-waste circular economy at a global scale in order to meet the sustainable development goals. The abstract addresses sustainable utilization of food waste and resource recovery including N from food wastes which would otherwise get leaked into the environment affecting the reactive-N balance.

WHEAT FLOUR FORTIFICATION FOR POST COVID NUTRITIONAL SUPPORT TO VULNERABLE SEGMENTS THROUGH FOOD DISTRIBUTION NETWORKS IN PAKISTAN

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Running Title: Fortified Flour Provision to Vulnerable Populations During/Post COVID Period

Background: Food and Nutrition Security is heavily threatened by the onset of COVID-19 pandemic, and Pakistan is no more exception. The most vulnerable segments including women and low wage workers are mainly relying on free or subsidized meals served by public and private sector managed food distribution networks (FDNs). These FDNs are mainly relying on wheat flour, which could be used as fortification vehicle to provide essential nutrients after fortification for Zn, Fe, Folic acid and B_{12}, during post COVID period.

Objective: This project was planned to ensure that wheat flour, procured by selected FDNs, was replaced with high quality fortified wheat flour in daily distribution meals, so that more nutritious foods would reach the most vulnerable segments in Pakistan.

Methodology: This pilot project executed through different private sector managed food distribution networks (FDNs), industrial distribution networks (IDNs), and ration distribution networks (RDNs), and their regular wheat flour was replaced with quality fortified wheat flour. After selection and agreement with flour mills and FDNs, their employees was capacitated to produce and serve quality fortified flour. Alongside the provision and monitoring of quality fortified wheat flour, supplied to FDNs, the fortification quality was also assessed for fortification compliance, through analysis of added iron content.

Findings: The agreements were signed with 11 flour mills, 11 FDNs, 6 RDNs, and 6 IDNs in 4 cities of Punjab i.e. Faisalabad, Lahore, Multan and Gujranwala; and 1 city of Sindh i.e. Karachi. Likewise, total 858 people from these flour mills, FDNs and provincial regulatory authorities were capacitated to provide quality fortified flour. During the project period June to December, 2021i.e. around 1,722 tons of quality fortified flour was produced by selected flour mills and 8.6 million fortified meals were served to the vulnerable consumers, including 61.50% male and 38.50% female population. Furthermore, the analysis revealed that the average content of added iron in case of all flour mills comply with the recommended fortification standards of Punjab Food Authority i.e. ≥15 mg/kg.

Conclusion: Micronutrient fortified wheat flour provision to vulnerable populations through these FDNs is one of the best strategy to be adopted both by government as well as private sector to compliment the basic nutrition of vulnerable segments.

Keywords: Food Distribution Networks, Fortified wheat flour, QA/QC, Vulnerable Segments

Biography: Dr. Muhammad Umair Arshad is currently working as Head of Food Science in Government College University Faisalabad, Pakistan. He has successfully completed some of the similar assignments with GAIN and other development partners in Pakistan as well as in Canada. The consultant is currently member of scientific panel of Punjab Food Authority as well as Sindh Food Authority, in addition to be the member of PSQCA scientific committees. It makes him quit fit for the capacity assessment study of Technical section on PFA. Moreover, the consultant is attached with teaching and research on food safety, specifically in small scale food processing operations, since 2006, which makes him potential candidate for the advertised consultancy. Dr. Arshad holds experience of 17 years on teaching and research for Food and Nutrition.

Assessing the Tradeoffs and Synergies Between Sustainable Development Goals and Nitrogen Management

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A knowledge gap exists between the extent and severity of on-farm nitrogen (N) surplus and its impact on sustainable development goals (SDGs). Understanding the interlinkages between N management and pursuit of the SDGs requires that we utilize existing data and statistical analyses to inform decision-making. Therefore, we use updated nitrogen use (Zhang et al., 2021) and SDG monitoring data (Sachs et al., 2022) to quantitatively assess the tradeoffs and synergies between crop N management and SDGs; thereby, helping to identify novel regional and economy-specific environmental and socio-economic policies as well as technological solutions for achieving SDGs and N waste reduction targets. We counted the number of significant Spearman's rank coefficients between N surplus reduction (i.e., the difference between N input and productive output for cropland, negatively transformed) and 113 normalized SDG indicator and goal index scores for over 150 countries. We identified the major SDG indicators that are in tradeoff or synergy relationships with reduction in N surplus based on observed proportions of significant negative and positive correlations, respectively, and with consideration for cases of insignificance. This ranking methodology was applied to both country income groups, as defined by the World Bank, as well as regional groups. For most SDGs, tradeoffs are more prevalent across both region and income-based groupings than synergies (i.e., an improvement of an SDG indicator's performance is more often accompanied with increased N surplus), and SDGs 3 & 9 ('Good health & Well-Being' & 'Industry & Innovation, Infrastructure') have the highest proportions of observed tradeoffs amongst all countries. With few exceptions, only SDGs 12 & 13 ('Responsible Consumption & Production' & 'Climate Action') are synergy-dominant at both the goal and indicator levels and across various country groupings whereas SDG 2 ('Zero Hunger') shows a complicated mixture of both synergy and tradeoff-dominant indicators. We hope to expand this analysis as a broader tool for understanding consequences of reducing N waste from agriculture.

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Nitrogen Footprint comparison of a Spanish Research Center under COVID-19 pandemic conditions

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The Nitrogen Footprint (NF) considers many processes, such as energy, food consumption and production, fertilizer usage, and other activities associated with the institutions. As part of an official institution, the research center INIA-CSIC has quantified its NF for 2019 and 2020, being the first research center in Spain to carry out this evaluation. The aim of this research was to quantify the NF of the research center INIA-CSIC to measure and identify the sources contributing to the release of reactive nitrogen into the environment. For that purpose, the NF was quantified and compared considering two years: 2019, as a considered normal activity year, and 2020, considered a special year where activity was reduced due to COVID-19 and lockdown. In 2020, the COVID-19 effects were evident in terms of the total NF generated within the boundaries studied of the research center. The total NF of 2019 for the facility of Puerta de Hierro of the research center INIA-CSIC was 9042 kg N, while for 2020 the total NF decreased as expected due to COVID-19, a total NF of 2986 kg N. In 2019, the highest nitrogen pollution was caused by food, in particular food production (96%) that releases nitrogen from fertilization, harvest, animal production, and waste processing. The second most polluting nitrogen source was utilities. Electricity and heating were responsible for a large portion of NF because of the reactive nitrogen released by the combustion of fossil fuel. Less nitrogen pollution, but still significant was the NF generated by transport caused by the usage of diesel and fuel by the institution's bus and private vehicles. Only 0.8 kg N was generated by the fertilization of gardens. Although the research center occupies an extensive area, the portion of gardens that require fertilization is small leading to a small NF for grounds keeping. Footprint from the utilities almost remained constant because of permanent experiments. This institutional NF approach serves INIA's institution as an indicator to assess their performance regarding N emissions and a way to identify targets to reduce its overall NF; and could motivate other research centers to quantify their NF to improve their N emission performance.

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The Portuguese nitrogen footprint, a challenge in a Mediterranean country

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A nitrogen (N) footprint quantifies and connects N losses with consumption patterns. This concept emerged out of the necessity to communicate the importance and the negative effects of N to the general public. Agriculture is the main source of reactive N (Nr) emissions to the global environment where beef and dairy products are responsible for 56% of Nr emissions in Europe. Regardless Portugal is a Mediterranean country, the typical Mediterranean diet is not followed at risk.

The N footprint of Portugal was estimated for consumption and production, based on Leach et al. (2012) approach, and compared to a typical Mediterranean diet N footprint. Total N footprint takes into consideration the footprints from energy consumption (housing and transport) and food consumption and production. For food consumption was assumed that all N consumed is excreted and released into the environment as human waste since the average adult does not incorporate N as muscle mass. For food production, the concept of Virtual Nitrogen Factor (VNF) was used where all Nr losses to the environment are accounted from the initial N input as fertilizer, per N consumption.

Preliminary result of the N footprint in Portugal is overall 25.1 kg N cap^{-1} yr^{-1}, estimated for the last year of available data (2018). Food production is the main contributor sector of the Portuguese N footprint (~ 80%), mainly from animal-based products, followed by food consumption, transport and housing sectors.

Considering the food wheel for Mediterranean dietary recommendations, food consumption and production N footprint in Portugal can achieve a reduction of 44% and 30%, respectively. Mediterranean diet has the potential to help mitigate N losses into the environment, not only in Portugal but across other Mediterranean countries.

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Wheat nutritional status estimation based on chemometric methods combining proximal and UAV-based measurements

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To increase Nitrogen (N) use efficiency (NUE), real-time crop N status assessment is important to adapt the N fertilizer rate by applying the right amount, at the right time, and at the right place to match crops' demand and avoid environmental losses. In this context, proximal and remote sensing offer good opportunities to optimize N fertilization. After evaluating the ability of proximal and unmanned aerial vehicle (UAV) based measurements to monitor wheat N nutrition index (NNI) during crop growths, we aim to study the interest of chemometrics methods to combine proximal and remote sensing measurements to increase the accuracy of NNI monitoring.

During three growing seasons (2020 to 2022), three field-trials showing various patterns of NNI dynamics were monitored in the North of France. Monitoring was made both on field with destructive measurements and with a leaf-clip sensor (Dualex, Force A, Orsay, France), but also with a six-lens modular multispectral camera (Kernel camera, Mapir, San Diego, USA) embedded on an UAV.

Firstly, the Dualex, through the NBI measurement (Chlorophylls/Flavonols ratio), presents a relevant application to predict NNI as the relation between NNI and NBI was good (R^2=0.78) and stable between years and varieties. Secondly, with the multispectral modular camera which was able to take images in 15 different wavelengths (from 405nm to 940nm), eight vegetation indices (VI) were calculated giving 248 different wavelength combinations. These 248 combinations were, then, evaluated to assess their predictive capacity for crop NNI determination. Because it was difficult to identify a consistent and robust wavelength combination to monitor NNI, partial least squares (PLS) regressions were built and evaluated to consider more explanatory variables than simple VI which combine only few wavelengths' measurements.

Finally, non-parametric models offer the opportunity to combine the benefits of proximal and remote sensing. This study confirms the interest of this combination, which allows to take advantages of these two measurement scales: proximal sensing accuracy and spatial heterogeneity consideration by remote sensing. A NNI monitoring model combining remote and proximal sensing measurements was therefore built from 2020 and 2021 dataset. These models were subsequently tested in a farmer's plot in 2022. The results from this study could be applied for dynamic N fertilization management. From such method, it would be possible for farmer to apply the right fertilization according to real-time crop needs.

Reabsorption of ^{15}N enriched ammonia by a winter wheat crop at two different growth stages

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Since ammonia has numerous negative impacts on the environment and human health the European Union has set the National Emission Ceiling (NEC) as an objective for the member states to reduce their emissions. Despite great efforts, Germany has only partially succeeded in reducing ammonia emissions over the last 30 years. The calculation of the emissions is based on emission factors (EF) which have changed numerous times over the last two decades. The EFs for different nitrogen-containing fertilizers depend on climate and soil pH. Because emissions only occur when ammonia is leaving the canopy and enters the atmospheric boundary layer, the crop and its growth stage are factors that influence the actual emissions, but there is only one EF for different crops and growth stages. Considering that winter wheat, the most important arable crop in Germany, can take up ammonia through its stomata there is likely a difference between the emissions that are calculated and the actual emissions at different growth stages due to reabsorption in the canopy of ammonia emitted at soil level. Earlier studies showed that this reabsorption is likely to occur in different field crops like wheat, tomato, coffee and grass-clover mixture. Since there are no recent studies available for winter wheat in Germany, this study was conducted within the NH_3-Min research project.

To estimate the reabsorption of ammonia by winter wheat, the ^{15}N enrichment technique was used. A solution of ^{15}N enriched ammonium sulfate was applied in containers open on the upper side between the rows of a winter wheat crop so that the ^{15}N could only be taken up by the wheat via ammonia absorption whereas uptake over the root was disabled. To enforce a uniform ammonia release from the ammonium sulfate solution, a sodium bicarbonate buffered sodium hydroxide solution (adjusted at pH 9) was added. Covering a total period of three days, the solution was exchanged every 24 hours. The total amount of simulated ammonia emission over these three days corresponded to a loss of 5 and 12.5 kg N ha^{-1}. After three days the wheat plants were cut and analyzed for its ^{15}N concentrations. To assess the influence of the growth stage on ammonia reabsorption, the experiment was carried out during stem elongation and flowering of the wheat.

We will present a poster showing the fully analyzed results of this experiment at the N workshop.

Reducing ammonia emissions from field applied fertilizers – comparing multi-plot approaches for ammonia measurements

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Ammonia (NH_3) emissions affect the environment, climate and human health. They stem mainly from agricultural sources and can reduce the nitrogen use efficiency of synthetic fertilizers. Such effects can be avoided by more refined fertilization technologies and strategies. To address uncertainties in the relative efficacy of such NH_3 emission mitigation measures, emission data from internationally accepted standard methods and valid mitigation assessments from replicated plots allowing statistical testing are of particular urgency. As part of the national cooperative project 'NH_3-Min' mitigation efficacies were simultaneously monitored under identical environmental and field management conditions.

The aim of this study is a comparison of methods for NH_3 emission measurement from field applied fertilizer on different scales. The experiments were carried out on five sites in Germany (centre (2 sites), south (2) and west (1)) in winter wheat. Investigated measures for NH_3 emission reduction from synthetic ammonia include (i) choice of nitrogen form, (ii) use of urease and nitrification inhibitors and (iii) liquid ammonium sulphate urea injection (CULTAN) beside the most common synthetic straight nitrogen fertilizers in Germany. In replicated quadratic plots with large interspaces (8 treatments, n=4, quadratic plots 81m^2), two types of acid samplers (sulphuric acid traps and Alpha samplers) and the open dynamic chamber system of the 'Draeger-Tube-Method (DTM)' were tested and cross-validated. The quantitative accuracy is checked and validated by micrometeorological measurements in circular plots including Integrated Horizontal Flux Method, backward Lagrangian stochastic dispersion technique (both involving different sampling approaches, 20 m radius).

DTM showed a high agreement with the micrometeorological method. Emissions from urea obtained by the two acid samplers correlated strongly with the results of the micrometeorological methods. Alpha samplers and acid traps significantly differentiated NH_3 emissions between treatments in the chosen experimental design. Alpha samplings were used to calculate quantitative ammonia emissions from small plots by inverse dispersion modelling ('Windtrax' software). In most cases, a close agreement between ammonia loss dynamics and cumulated emissions from small and large plots supplied with urea fertilizer was observed. Ammonia mitigation technologies showed varying efficacies, the strongest reductions were observed for urea treated with urease inhibitor, the effect being less pronounced in UAN.

The paper will present the set-up, objectives and a first overall evaluation of the measurement techniques used. The project is supported by funds of the German Government‘s Special Purpose Fund held at Landwirtschaftliche Rentenbank.

NH_3-Min project: Reducing NH_3 losses from application of synthetic nitrogen fertilizers and increasing nitrogen use efficiency of fertilization

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Ammonia (NH_3) emissions stem mainly from agricultural sources and affect environment, climate and human health, thereby concomitantly reducing fertilizer nitrogen use efficiency (NUE). Against this background, the reduction of NH_3 losses originating from the use of synthetic nitrogen fertilisers has gained political importance. However, there is a lack of data on simultaneous comparative evaluations of mineral fertilizers for the assessment of fertilisation strategies and NH_3 mitigation options under identical conditions. The joint research project NH_3-Min is aiming at analysing and assessing measures to reduce ammonia emissions from application of synthetic fertilizers and to increase fertilizer NUE. The focus is on the most common synthetic nitrogen fertilizers in Germany, i.e. urea (U), calcium ammonium nitrate (CAN), urea ammonium nitrate solution (UAN) and urea ammonium sulphate (UAS). Options for mitigation of NH_3 emissions are evaluated, such as (i) choice of nitrogen form, (ii) use of urease and nitrification inhibitors (UI, NI) and (iii) UAS injection (CULTAN). In order to simultaneously assess different measures to mitigate NH_3 losses, randomized multi-plot experiments have been set up at 10 sites across Germany covering different climatic regions and soil types. This assessment is based on a combination of different sensors and flux calculation methods and is tested and cross-validated on different spatial scales. Ammonia measurement systems include acid samplers (acid traps, Alpha samplers) and dynamic chambers on the multi-plot scale, the accuracy of which is checked and validated by micrometeorological measurements including the Integrated Horizontal Flux (IHF) method, inverse dispersion modelling (both involving different sampling approaches) and eddy covariance measurements. Experiments have been carried out with winter wheat since 2020 and in the following three years. The project set-up, aims and preliminary results are presented.

The project is supported by funds of the German Government‘s Special Purpose Fund held at Landwirtschaftliche Rentenbank.

Cover crop's effect on agricultural soils mineral N dynamics and nitrous oxide emissions

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Agricultural soil constitute a substantial source of anthropogenic Nitrous oxide (N_2O) emissions. Atmospheric N_2O concentration have increased by about 23% since the industrial revolution. This is caused partially due to the increase use of nitrogen fertilizers required to meet the growing human population's demand for food and biofuels. Cover crops have been shown to effectively decrease N leaching by taking up excess N in autumn. The effect of cover crops on N_2O emissions however is still not clear, as contrasting results have been obtained by previous studies. In this study, we aimed to quantify the effect contrasting cover crops have on N_2O emissions and soil mineral N (Nmin) dynamics in a sugar beet – winter wheat crop rotation in Germany. We compared three contrasting cover crops: a frost tolerant grass (winter rye), a frost sensitive grass (Saia oat) and a leguminous cover crop (summer vetch) to fallow treatment as the control. We conducted our trials in two sites in Germany: central and south-west Germany with two trials per site starting in autumn of two consecutive years (2018 and 2019). Using the closed-chamber method, we measured gas fluxes at least once a week for the duration of 1.5 years per trial. Cover crops have effectively taken up N in fall and significantly reduced Nmin content in topsoil. N_2O emissions varied spatially and temporally and peaked after heavy rain events, N fertilization, soil cultivation and incorporation of plant residues. Frost-sensitive cover crops emitted more N_2O emissions in the cover crop phase than non-frost sensitive and fallow treatment. Soil plowing combined with a higher biomass of cover crops lead to higher N_2O emissions when compared with soil tillage. We observed no effect of cover crop treatment in the second main-crop phase (winter wheat) in regards to soil Nmin and N_2O emissions. For the cumulative direct N_2O emissions, we found no significant difference between the treatments. Additionally in this study, Grunwald et al. (2022), found a positive effect of all cover crop treatment on soil properties and early sugar beet growth. Thus, we conclude that cover crops have a net positive effect and are advised to be included in crop rotations. The effect of cover crop mixture, different agricultural practices such as soil cultivation and cover crop mulching should be further studied concerning Nmin Dynamics and N_2O emissions.

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Optimising N2O measures following the application of mineral and organic nitrogen fertiliser to sugarcane

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Agricultural soils are the most significant source of the major greenhouse gas N_2O (Reay et al. 2012). Sugarcane production has an important contribution to these emissions (Yang et al. 2021). There is limited information related to optimising N_2O emission measures, in particular for organic fertilisation, which could greatly reduce the cost and time spent in measures. Datasets from a highly instrumented experimental site in Reunion Island were analysed with the aim of minimising manual chamber N_2O emissions, while ensuring that reasonable accuracy of N_2O emission evaluations is maintained for the mineral fertiliser urea, and for two organic fertilisers, namely sewage sludge and pig slurry. Manual chambers remain the most accessible and widely used apparatus for N_2O emission measurements.

Continuous N_2O emissions were monitored over three sugarcane ratoons (between 2018 and 2021) using automatic chambers, and the data was interpolated to simulate manual sampling scenarios over the sugarcane growth-cycle, which was compared to daily N_2O emissions. Additionally, the number of measures required for each sampling over 60 minutes were tested using manual chambers, as well as the inter-row placement of chambers.

There was no significant difference ($p<0.01$) in emission values when 5, 4, 3 or 2 measures were taken over a 60-minute interval. The position of the manual chamber between sugarcane rows also did not have a significant impact. The sampling scenarios revealed that both bi-weekly sampling over the first 6 months of the ratoon, as well as 48 samples strategically placed over the ratoon relative to the emission patterns of each fertiliser type, were suitable for measuring N_2O emissions. These scenarios resulted in no extreme deviations from the daily measures for the urea and pig slurry fertilisers (< 10 % difference), and for sewage sludge (< 20 % difference).

The findings can be used to inform appropriate protocols to reduce cost and time spent in N_2O measurements without reducing the accuracy of N_2O emission results.

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Organic vs. synthetic fertilization of silage maize: N_2O emissions from digestate and urea

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Replacing synthetic fertilizers with digestate shows great potential to maintain high yields while reducing the environmental impact of fertilizers production. However, its mismanagement risks to cause high N_2O emissions. The aim of this study was to evaluate the soil N_2O emissions of digestate and urea providing information about the environmental impact related to the direct use in field. GWP and yields assessment were used to understand the environmental and food security potentials of each fertilizer. The experiment was conducted for a three years (2016/2017/2018) in Florence (43° 47' 07"N 11° 13' 11" E), on twelve tanks of $1m^3$ filled by a silty-clay soil. Soil was collected from a field northern to Florence (43° 58' 56"N, 11° 20' 55"E), and divided in three profiles (0-30; 30-60 and 60-90 cm depth) to replicate the natural profile. Silage maize (var. Ronaldinho) was sown with a density of 12.000 plants ha^{-1}. A drip irrigation system was set to ensure water supply. Fertilization treatments, four replicates each, were: (i) liquid fraction of digestate from pig slurries and agricultural by-products (150 kgN ha^{-1}); (ii) urea (150 kgN ha^{-1}); (iii) no fertilization (control). Digestate was manually spread, replicating slurry injection. N_2O emissions were monitored using the static chamber methodology (Charteris et al., 2020) and a portable gas analyzer (Madur Sensonic). Measurements lasted from fertilization until no emissions were detected. N_2O fluxes were calculated using gas concentration, chambers closing time, molecular weight of N_2O, chamber area and volume. Yields (dry weight) were determined harvesting the entire plants and drying the biomass for 48 hours at 80°C. Digestate showed the highest ($p<0.001$) N_2O emissions (1.66 kgN ha^{-1}±0.60) in the three years. The high water content and the injection, favored the infiltration of digestate into the soil as well as the interaction with the microbial community. This, together with the high organic C content, favored N_2O emissions. Due to extreme dry conditions, in 2017 emissions from all treatments were lower than 2016 and 2018. Digestate and urea showed similar yields, 12.58±0.52 and 12.08±0.55 t ha^{-1}, respectively, confirming the role of digestate as alternative to synthetic N fertilizers. As for N_2O emissions, during 2017 yields were lower than 2016 and 2018. Again, the main cause was drought, as confirmed by the morphology of the plants, which appeared with lower growth. The analysis of cumulative impacts (production process and use) reported a greater impact of urea than digestate (1239.49 and 493.36 kg CO_2 eq, respectively). This was because urea is an industrially produced fertilizer and that digestate is assumed to have neutral impact, as by-product of biogas. Digestate is an effective strategy to reduce the use of synthetic fertilizers and their impact from the production process while maintaining high yields. However, the high N_2O emissions during digestate use in field is the major criticism reducing the efficiency of this strategy.

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Greenhouse gas emissions from cultivated soils *vs* riparian areas in the Sorraia Valley, Portugal

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The effect of climate change continues to impact health, environment, and economy. Thus, it is increasingly necessary to understand the factors that control greenhouse gas (GHG) concentrations (N_2O, CO_2, CH_4) in the atmosphere. The specialization of agriculture, such as through the implementation of various irrigation practices, together with the improvement of high-yield crops and the application of large amounts of fertilizers and pesticides, has already proved to be effective in increasing agricultural production. However, such highly productive agriculture can also negatively impact the environment if practices are not appropriately applied (FAO, 2009). Also, recent research suggests that riparian areas may also be important contributors of GHG emissions to the atmosphere in agricultural areas due to their intense biogeochemistry (Vidon et al., 2015).

Within the scope of the AgroGreen Sudoe project, we have started to measure CO_2, N_2O, and CH_4 since 2021, within the Irrigated Perimeter of the Sorraia Valley, in Portugal, using static chambers. GHG emissions measurements were performed in four sites: i) a farmer's field cultivated with maize irrigated by a center pivot; ii) a farmer's paddy rice field; iii) a riparian zone under trees; and iv) a riparian zone with herbaceous vegetation. At each site, three replicates were considered. In the riparian zones, sampling was performed monthly, while at the cultivated fields the sampling frequency was adjusted according to the fertilization treatments. At the same time, soil samples were collected near the surface and analysed for N and organic C. In the maize field, soil moisture and soil temperature were monitored continuously at the depth of 15 cm using capacitance probes.

The first data obtained in this study are still under analysis but will provide some relevant information for this region and might possibly allow to refine some emissions factors. Furthermore, it will give some support to establish some mitigation option.

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Understanding cover crop traits as drivers of nitrogen losses

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Cover crops are a powerful tool to reduce nitrate leaching losses. However, their potential to reduce N_2O emissions has been little studied, and the main cover crop traits driving the effects on nitrogen (N) losses remain poorly understood. Therefore, we conducted a greenhouse experiment with cover crop pure stands, covering a wide range of morphological, architectural, physiological, and biotic traits. The treatments were grasses (ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), oats (*Avena sativa*), and rye (*Secale cereale*)), two legumes (red clover (*Trifolium pretense*), and vetch (*Vicia sativa*)), two brassicas (white mustard (*Sinapis alba*), and radish (*Raphanus sativus*)) and two forbs (plantain (*Plantago lanceolata*), and chicory (*Chicorium intybus*)), and bare fallow (control). Inorganic N was added in two events: 30 kg N ha^{-1} before seeding, and 50 kg N ha^{-1} eight days after seeding. We found that cover crop presence decreased N_2O emissions (40%), N leaching (58%), and soil NO_3^- concentration (60%) compared to bare fallow. In general, cover crop species identity explained more of the variation of plant N uptake, N losses and soil inorganic N pools than cover crop functional groups. Higher N uptake was linked to lower N_2O emissions, N leaching and soil NO_3^- concentration. Among the cover crop species, *Raphanus sativus* had the lowest N leaching and lowest N_2O emissions (together with Lolium perenne). This species had one of the lowest leaf dry matter contents (LDMC), the lowest leaf N content (LNC), and the largest root diameter. Although plant traits individually were not good predictors of cover crop effects on N losses, the combination of these traits in *Raphanus sativus* resulted in high plant biomass production and high N use efficiency (g biomass per g N uptake). In turn, this species with a high level of N scavenging, reduced soil NO_3^- concentration, and thereby N losses. Overall, these results shed light on the main cover crop suit of traits required to achieve substantial reductions in N losses.

Effect of crop diversification on soil N_2O emissions in semiarid Mediterranean conditions

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Mediterranean semiarid agroecosystems represent a challenge for agricultural sustainability due to the limited precipitation and low soil quality, typical of this area. Besides, since the second half of the 20th century, the intensification of agriculture has led to large N-fertiliser applications for increasing crop yields. Excessive N fertilization has an impact on soil N dynamics, contributing substantially to global warming by the loss of N in the form of N_2O (Venterea et al., 2012). Diversified cropping systems based on the introduction of legumes, due to their N-fixation ability, could have a great potential for reducing the N-input to agroecosystems, and thus minimize N losses. Our study aims to evaluate the effect of diversified cropping systems compared to cereal monoculture systems on the soil N_2O emissions in Mediterranean semiarid conditions.

For this purpose, a long-term field experiment was conducted under rainfed conditions, located in Zaragoza (NE, Spain). Two crop rotations (wheat-barley and barley-pea) under no-tillage were compared for the evaluation of possible alternatives to the traditional barley monoculture. Soil N_2O emissions were quantified every two weeks from sowing (October) to harvest (June) and every three weeks from harvest to the next sowing (summer fallow) during four growing seasons: 2018-2019, 2019-2020, 2020-2021 and 2021-2022. Associated to each gas sampling, soil moisture (0-10cm) and soil surface temperature (10cm) were recorded.

The results indicated that the cropping system impacted the soil N_2O emissions in the study conditions. The inclusion of legumes in crop rotations has great potential for reducing soil N_2O emissions associated to fertiliser applications. Nevertheless, diversified systems with legumes under no-tillage require a better management for minimizing N_2O losses in Mediterranean semiarid conditions.

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Effects of different nitrogen fertilization sources and rates on nitrogen use efficiency and N_2O emissions of tropical forage grasses

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Nitrogen (N) fertilization plays a notable role in global food security since it has improved productivity of cropping and livestock systems. However, the excessive use of synthetic N has negative economic and environmental effects. The objective of this study was to evaluate the influence of different N sources and application rates on the productivity and N use efficiency of three common pastures of tropical lowlands, *Urochloa* hybrid cv. Cayman, *Megathyrsus maximus* cv Mombasa, and *Cynodon nlemfuensis* - Stargrass in a cattle grazing system located in the municipality of Santander de Quilichao, Cauca – Colombia. In a first phase, we evaluated four N sources at a rate of 25 kg N ha^{-1} (urea; calcium ammonium nitrate (CAN); urea/ammonium sulfate (U-AS); and native soil N as control) to determine differences in forage dry matter production (DM) after 28 days, nutritional quality, total N uptake, N use efficiency (NUE) indices and N_2O emissions (genotypes with higher NUE).Then, the sources that promoted the highest NUE in each grass species were selected for a second phase evaluating different rates of N application (0, 10, 20 and 30 kg N ha^{-1}). CAN stimulated the greatest increase in the height of the grasses, and along with urea both fertilizer treatments showed 22% greater DM than the control without added-N. The fertilized treatments showed higher total N uptake than the respective controls. The CAN source improved apparent N recovery by approximately 38% with respect to U-AS in all grasses. Agronomic N efficiency in urea-fertilized pastures were more than twice as high as those fertilized with U-AS. The highest NUE was achieved with 20 kg N ha^{-1}, with 93% efficiency. Cayman pasture with a rate of 20 kg N ha^{-1} had a higher dry matter (DM) production than with 30 kg N ha^{-1} (i.e., 22% more) and 47% less N_2O total emissions that translated into 1.65 µg N-N_2O kg DM^{-1} of emissions intensity. In Stargrass, the 20 kg N ha^{-1} rate allowed an increase in productivity and a decrease in N_2O emissions with respect to the other rates; the emissions intensity was 4.6 µg N-N_2O kg DM^{-1}. Mombasa grass with 30 kg N ha^{-1} showed an increase of approximately 60% in dry material productivity, at a lower emission cost (1.43 µg N-N_2O kg DM^{-1}). With these results it is possible to conclude that the use of adequate sources and doses of nitrogen fertilization improve NUE and reduce N_2O emissions.

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Nitrous Oxide Emission Dynamics in Sri Lankan Paddy soils under controlled water management

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Paddy ecosystems constitute a dominant source of nitrous oxide (N_2O), a high potent greenhouse gas responsible for global warming and regional climate shifts. Paddy is typically grown in fully submerged conditions thus providing favorable anaerobic environment for denitrification driven N_2O production. Due to intense pressure on water availability, however, novel strategies such as alternative wetting and drying (AWD) have been introduced to optimal water usage without compromising the yield. The impact of such new water management strategies on N_2O emission has not been adequately studied particularly in South Asian paddy systems. In a field-scale experiment conducted at the experimental site in Rice Research and Development Institute in Sri Lanka, this study investigated N_2O emission dynamics under CF (I.e., completely flooded throughput the paddy cycle) and AWD (i.e., with mid-season drainage to -15 cm, followed by re-flooding). Experiments were conducted under four treatments in randomized plots with paddy plants (P) and without paddy plants (NP) using the same rice variety. All treatments received equal amounts of fertilizer according to the conventional local farming practices at the rate of 35 kg/ha of triple superphosphate (TSP), 30 kg/ha of carbamide and the 75 kg/ha of carbamide and muriate of potash mixer at 14 and 45 days after transplant (DAT), respectively. Emission of N_2O was measured periodically using closed chamber technique and collected gas samples were analyzed using gas chromatography. Significant N_2O emissions were observed with rice plants under both CF and AWD as compared to without plants, while the peak in N_2O flux (30.2 mg N_2O m^{-2} h^{-1}) occurred under the AWD/P treatment. Highest N_2O fluxes under AWD with draining and intermitted flooding is attributable to the transition from anaerobic to aerobic soil conditions and the top-dress application of supplemental fertilizer. Under the CF condition, N_2O emission takes place predominantly through the aerenchyma of the rice plant for dissolved N_2O from root zone to atmosphere while draining caused diffusion controlled N_2O emissions through the soil. Rice grain yield did not differ significantly among the CF and AWD treatments despite the reduction in water usage in AWD by 45.6% as compared to the CF. However, the seasonal cumulative nitrous oxide emission was reduced in CF by 29.2% as compared to the AWD. The results thus emphasize the need of careful site-specific management options to sustain the N_2O emission under different water management strategies.

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Enhancing nitrogen use efficiency in global livestock supply chains

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In the past decades, the growth of the livestock sector has significantly altered nitrogen (N) flows due to the geographical concentration of animal farming in regions with low production costs. While livestock provide food security and livelihoods to billions of people, it is also associated with externalities such as greenhouse gas emissions or nitrogen pollution. Livestock supply chains are responsible for approximately one third of anthropogenic N emissions. These emissions are unevenly distributed across regions, with about 66 percent emitted in Asia. Enhancing nitrogen use efficiency in different stages of the life cycle of livestock products can reduce environmental pressure, thus resulting in high incomes for farmers. Several mitigation options are available to enhance nitrogen use efficiency but it is necessary to assess their cost-effectiveness, in particular, given the current high prices of fossil fuel energy and synthetic fertilizer.

Taking advantage of drainage water from a modernized irrigation district in the Ebro basin to reduce the nitrogen input in downstream traditional district.

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Impact of agricultural drainage in downstream ecosystems has been severally studied (Blann et al., 2009). There are different ways to reduce this impact, such as improving the fertilization and irrigation management at field and basin scales, selecting crops with less water and nutrient requirements or the use of green barriers which act as sinks. In some cases, it may also be possible to reuse this water before it reaches downstream rivers. In this research, we studied the irrigation water in terms of both quality and quantity from the main drainage outlet (which drains 2587 ha of irrigated crops) of the Algerri-Balaguer irrigation district (Ebro Basin, NE Spain). Exportations during 2021 were 2.91 hm^3 of water with an average electroconductivity (EC_d) of 3.42 dS/m at 25 ºC, this data was acquired using a HYDROS 21 sensor (METER Group, USA), which provide hourly data of water level (mm) and EC_d. Moreover, monthly analysis with Nitracheck 404 (KPG Products Ltd, UK) showed an average content of 101 mg NO_3^-/L or 22,8 mg N/L. This water is leaded through a channel that borders the *sèquia d'Albesa* traditional irrigation district, which grows mainly corn and orchard trees with a maximum consumption of 9000 m^3/ha. After that, it ends up in the Noguera Ribagorçana river. Considering the water volumes with its nitrate content, this study concluded that reusing 100% of this drainage water implies for 1024 ha of the *sèquia d'Albesa* irrigation district an average application of 64 kg N/ha, resulting an overall reduction of fertilizer application of 65,500 kg of N for the entire district. The need to improve fertilization management is undeniable, but in the meantime tools such as drainage water reuse can be a good way to reduce downstream impacts of agriculture.

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Agronomic evaluation in different crops of a bio-stabilized Municipal Solid Waste

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New European Guidelines are encouraging the re-use or recycling of secondary materials. This approach, based on waste recycling and recovery, seeks to replace the traditional linear economy with a circular economy. In line with this initiative, the utilization of the organic fraction of the Municipal Solid Waste (MSW) once treated in a bio-stabilization process for agronomical purposes aims at expanding the useful life of this by-product. Some greenhouse experiments with wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), faba bean (*Vicia faba* L.), and buckwheat (*Fagopyrum esculentum* Moench) were conducted at the National Institute for Agricultural Research (INIA), sited in Madrid (Spain). The treatments combined two types of fertilization, mineral and organic (and the control without fertilization) with two types of soils (sandy and clay soil), during different years. The treatments were arranged with three replicates. Mineral fertilization and organic fertilization with bio-stabilized MSW amendment (provided by Urbaser Company) were equivalent on N rates.

A positive response of biomass production and seed yield was obtained in the organic fertilization treatments regardless of the crop type, obtaining comparable results with respect to the mineral fertilization treatments. Additionally, organic fertilization significantly enhanced seed quality and nutrient content compared to mineral fertilization, which resulted in higher chlorophyll content. Soil properties, such as organic matter and nitrogen content, as well as soil nutrient concentrations, were positively affected by organic fertilization, presenting adequate levels of heavy metals concentration, which did not exceed the regulated limits. In general, under very fertile conditions, such as fertilized clay soils, the crops were able to increase crop yield and nutrient uptake. Reusing bio-stabilized MSW for agronomical purposes can add value to this waste product, serving as an effective alternative to mineral fertilizers for different crops.

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N and C in composting processes: Mass balance and GHG emissions.

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Composting is the most widely used waste management technique treatment system worldwide. Although one of the main interests of composting is its potential to reduce GHG emissions, it can also lead to their formation. Therefore, there is a growing interest in the study of direct GHG emissions of large-scale windrow composting method and in the search for management practices that minimize their production. The characteristics of the starting nitrogen (N) and carbon (C) resources affect the physic-chemical properties of the pile and consequently govern the processes leading to the formation, diffusion and transport of GHGs. In this context, the main objective of the present study was to evaluate the impact of composting process on mass balance, methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions.

In this work, GHG emissions were monitored in 18 piles of ternary co-composting from waste pomace of olive oil (alperujo, 65% f.w. in all the piles) with different sources of N from manure (20% f.w. in all the piles) and different sources of C as bulking agents (15% in all the piles) using windrow piles of 15 m^3 operated at commercial management. The experiment was carried out in the Agrocomposting Plant of Sant Mateu (Castellón, Spain). Six experimental blocks of three piles each were established in relation to the type of N source used: monogastric animal manure (poultry manure and solid fraction of pig slurry), ruminant manure (cattle and sheep manure) and stabilized biowaste (from two urban household treatment plants in Valencia region). In each block, the piles were combined with different bulking agents as a source of C: olive leaves, urban pruning waste and the combination of both (1:1, v/v ratio).

Gas sampling was carried out using static chamber technique (Viguria et al. 2015) at 0, 7, 15, 30, 52, 65, 79, 100 & 120 days of composting. Samples were analyzed by gas chromatography (Agilent 7890A). The cumulative emission of CH_4, N_2O & CO_2 and GWP were calculated. Significant differences were found linked to N sources in composting piles on GHG fluxes, being especially high for poultry manure. The bulking agents used induced low effects on dynamics of GHG emissions, some of them (olive leaves) favoring higher emission of CO_2. The concentration and nature of the N source into the pile significantly affected also the N_2O emissions.

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The potential of N recovery from agrofood waste: the case study of Valencia Region (Spain)

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Circular economy proposes the waste management as principal pillar to create a secondary resource market. However, the production of organic waste in agrofood sector (agriculture, farming, forestry and food processing) is not well known but specially the main characteristics of the different fluxes produced. In addition, in most of the cases, the necessary decision systems to select/apply the different alternatives for organic waste valorization are not developed or transferred to the actors with significant losses of nutrients and organic matter in sensitive regions vg Mediterranean area. There are also significant synergies that boost this circularization trend such as the need to eliminate agricultural burns, the promotion of soil sequestration of C and the mitigation of greenhouse gas emissions, as well as the selective collection at source of the organic fraction of urban waste that favor agroecological management schemes as a whole.

The Agrocompostaje Project (https://giaama.umh.es/) is an initiative of Conselleria de Agricultura, Desarrollo Rural, Emergencia Climática y Transición Ecológica of the Valencia Government and Miguel Hernández University to promote nutrients and organic matter recovery from agrofood wastes. One of the main actions is to monitor the organic waste fluxes. In the last 5 years a database of more than 340 materials were georeferenced, quantified and analyzed. Agricultural wastes (n=88) included 1.5 Mt/year in the region (35% water content), with an average value of 1.3% N d.w. and 43.1% of C. Agrofood sector generates a wide range of organic waste linked to food processing, more than 0.8 Mt/year, with and average N content (n=132) of 1.7% d.w. and 47% of total C. Finally, the manures produced in Valencia region, VR (n=118) showed the highest concentration of N (2.4% d.w.) and the lower total C (35% d.w.).

This monitoring study allows us to obtain the potential biomass in VR according to Alfonso et al. (2009) methodology, related to the Valencian administrative areas ("comarcas") and also propose co-composting synergies to minimize nutrient recovery with lower GHG and C footprint oriented to the production of high quality biofertilizers in a more sustainable and circular agriculture.

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Filters made by waste to fix N gas emissions from slurry

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Deposits of pig slurry are a great source of Green House Gasses (GHGs) and ammonia (NH_3) emissions, pollutant gases that contribute to climate change and damage human health. However, pig slurry is a source of nitrogen and therefore, a potential fertilizer source when adequately managed.
The objective of this project is to evaluate ~24 wastes as filters to capture GHGs and NH_3 emissions by physical, chemical, or photocatalytic reactions to obtain a double benefit, reduce pollution and be used as potential fertilizers.
A large waste screening based on intrinsic properties of the wastes was performed to choose the most appropriated according to the project objectives'.
Around five cm^3 (1-4 g) of each waste were analyzed after gases derived from the volatilization of 40 mL of pig slurry passed through it. Waste samplings in triplicate were taken 10, 25 and 45 days after implementation (DAI) to know their ability to capture these emissions with time.
The 24 different wastes showed different retention curves along the 45 DAI. The N gases retention varied from ~0 mg N per kg of waste to 1000 mg N per kg of waste. However, the percent of N retention from the total N volatilized —from the 40 mL of slurry—was relatively low (~3%). This low percentage could be attributed to the high temperatures applied (26°C) and due to the low retention time through the filter (3 mm wide), as well as the lack of properties to retain ammoniac. Additional work with the different wastes as filers is going on to enhance N gas capture.

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Circular Economy Model of Nitrogen Management and Bioenergy Production from Waste Water

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European Green Deal and circular economy action plan has been developed and the main focus of this plan is to reduce waste volume and promote the introduction of circular patterns in reactive nitrogen management. Particular attention shall be paid to reducing the amount of nitrogen waste through separate collection and labelling. In addition, a bioeconomy strategy covering all sectors and systems based on nitrogen rich biological resources should be mentioned. It covers and links all terrestrial and marine ecosystems and their diverse services. The bioeconomy strategy is based on the principles of sustainability and the circular economy of nitrogen and other resources. The assessment of current objectives and the need for the most sustainable use of available resources prompts the search for alternatives in already established technologies. Biological purification plants consume a large amount of energy that is mostly obtained from fossil resources and do not recirculate nitrogen. By implementing an alternative household wastewater purification method - phytoremediation by the use of willow in underground stream wetland allows for a sustainable use of nitrogen resources and saves energy as household wastewater purification is performed by natural means. More-over, wood chips are obtained from willow which is used in energy generation. The aim of the research is to develop a circular economy model for willow used in wastewater phytoremediation. The hypothesis of the research is the following: The household wastewater purification method which uses willow for phytoremediation in underground stream wetland complies with the circular economy model. Calculations are made in the research in regards to the pilot territory for Nakotne village in Latvia. The following parameters were calculated in the paper: the necessary area for creating the underground wetland, the cost of it and also the benefits obtained from the wetland (the amount of energy generated, CO_2 accumulated, oxygen created), and the ability of willow to accumulate polluting elements (nitrogen and phosphorus) present in household wastewater was researched. After assessing the information obtained in the calculations it has been implemented in the proposed circular economy model. It is concluded in the research that willow has potential in household wastewater purification and that the proposed model of willow planting in underground stream wetland complies with the principals of circular economy model.

Emergy approach to the sustainable use of ecosystems towards better land management

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A holistic approach to agricultural systems relies on farm management practices and thus, its financial support and incentives. The economic quantification of the environment is yet to be appropriately assessed, being subjected to subjective approaches such as the “willingness-to-pay”, the opportunity costs and remediation costs for sites that require corrective action. Resource use optimization is intrinsic to ensure long-term agricultural productivity. In this sense, emergetic assessment is presented as a solution to evaluate the efficiency and environmental impacts of agricultural systems, which are often complex. Sustainable economic and environmental decision making is therefore supported by emergetic approaches. These include key agricultural factors such as the net yield, environmental load and use of non-renewable resources. These factors have a strong influence on the choices and management practices which will shape and determine the sustainable use of the ecosystem.

Emergy is defined as the sum of energy inputs used directly and indirectly, during a process, to make a product or service. This method provides a set of indices which are functions of renewable, non-renewable and purchased emergy inflows. Hereafter, strategies to maximize the sustainable use of agricultural ecosystems, without compromising its production, can be assisted with the indices of yield, investment, environmental loading and sustainability.

Keywords: emergy, emergy indices, sustainability, agriculture

Revealing stakeholders' perceptions of N-fertilizing practices in SUDOE herbaceous agroecosystems

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Agronomic practices are associated with a complex combination of positive and/or negative impacts of different nature (i.e., yields, soil properties, costs, etc.). As a result, stakeholders' views on different agronomic practices are heterogeneous or even opposed, and within a same stakeholder group individual opinions may differ. Such a diversity of opinions can reveal the existence of barriers to the reduction of N losses in agriculture but can also provide clues to the overcoming of such barriers or to the identification of opportunities for the adoption of best fertilizer-management practices towards N neutrality in agroecosystems. In this research we use Q methodology to map stakeholders' views about agricultural practices in three herbaceous farming regions of the SUDOE (Southern EU) territory: the Garona basin in France, the upper and middle Tagus basin in Spain, and the lower Tagus basin in Portugal. We conducted interviews to two types of stakeholders (farmers and experts), that were asked about the priority that should be given to the implementation of 34 agronomic practices, including N fertilization methods. With this research we aim to identify the main differences and similarities on how stakeholders perceive agronomic practices and their relation to optimal land management regarding nitrogen use efficiency and enhanced sustainability of agroecosystems.

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Comparison of the ammonia trapping performance of different gas-permeable tubular membrane system configurations

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Gas-permeable tubular membrane (GPM) technology holds promise to reduce ammonia emissions from livestock manure, by capturing NH_3 in an acidic solution and obtaining end products suitable for valorization as fertilizers, in line with circular economy principles. The objective of this study was to evaluate the performance of a membrane system consisting of both a submerged and a suspended membrane for the recovery of NH_3 released from pig slurry (4000 mg TAN·L^{-1}), comparing it to other types of system configurations. Four configurations were tested: (S1) system consisted of submerged + suspended GPM inside an airtight chamber with agitation and an aeration rate of 0.24 L air/(L slurry·min); (S2) system consisted only of a suspended GPM inside the chamber under the same conditions as S1; (S3) system consisted of a GPM suspended inside the chamber without agitation and aeration of the slurry; and (S4) system consisted of a GPM suspended in an adjoining compartment with an air suction rate of 200 L·h^{-1} from the chamber with slurry to the adjoining compartment. Sulfuric acid (1N H_2SO_4) was chosen as the NH_3 trapping solution, circulating at a flow rate of 2.1 L·h^{-1} inside the membranes. The results showed that the NH_3 flux values were in the following ranges: 5-6 g·m^{-2}·d^{-1} in S3, 10-11 g·m^{-2}·d^{-1} in S4, from 16-18 g·m^{-2}·d^{-1} in S2, and 22-23 g·m^{-2}·d^{-1} in S1, with significant differences among all of them. The highest NH_3 recovery rate was achieved using S1 (78-81%), followed by S2 (69-74%), S4 (66-72%), and S3 (49-59%). These recovery rates were higher than those reported in the literature for submerged + suspended GPM systems, of up to 48% (Majd et al. 2013). Even though improvements of up to 30% in NH_3 capture efficiency may be attained depending on the GPM system configuration, investment and operating costs (also analyzed in the study) should also be taken into consideration to choose the most suitable option for each application (NH_3 trapping from livestock buildings, manure storage facilities, composters, etc.).

Keywords: ammonia recovery, gas permeable membrane, suspended GPM system, submerged GPM system.

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LIFE Green Ammonia project: Market technology based on membranes for ambient ammonia reduction in livestock farms

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Conservation and recovery of nitrogen from livestock manure is of key importance in agriculture but entails other associated advantages from an environmental and an economic perspective: it can contribute to decreasing ammonia emissions into the atmosphere and the recovered ammonia may replace commercial fertilizers as a nitrogen source. The application of gas-permeable membranes (GPM) for capturing NH_3 from the ambient air of livestock housing has been previously demonstrated in the LIFE Ammonia Trapping project, in which a prototype was designed, constructed, and tested for the *in situ* recovery of N from the atmosphere of pig and poultry farms and composters (Soto-Herranz *et al*. 2021a, 2021b). In the pig farm, ammonia recovery efficiencies were on average 2.3 g/(m^2·day), observing a great influence of ventilation, with efficiencies of 1.6 and 3.9 g/(m^2·day) in the summer and winter periods, respectively. In the laying hen farm, average efficiencies of 0.4 g/(m^2·day) were attained, with actual efficiencies ranging from 0.3 to 1.2 g/(m^2·day) in summer and winter, respectively, also as a result of the strong influence of ventilation. Finally, in the composting process, efficiencies in the 1.9 to 6.9 g TAN/(m^2·day) interval were obtained, depending on whether the GPM prototype was directly installed in the composter or connected to it as an external module. Based on this previous experience, in the LIFE Green Ammonia project, GPM technology for reducing NH_3 emissions at a commercial scale is currently under development. The goal of the project is to design, build and test a more efficient commercial model able to reduce ammonia emissions from N-rich waste (e.g., pig and poultry manure) by 35%, obtaining a nitrogenous mineral fertilizer with high agronomic value.

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An integrated innovative approach for sustainable delocalization of manure nitrogen in orchards

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In high-density livestock areas manure nutrients availability often exceeds crops need inducing nutrient losses to the agroecosystems. These losses happen in the form of atmospheric emissions, runoff and leaching, affecting air and water quality and biodiversity. New and efficient manure management tools and solutions are needed to face this issue and allow to redistribute plant nutrients in area where their availability is scarce. In this context, the Life Agriclose project (https://agriclose.eu/it/cover/) developed an innovative, integrated, approach for a sustainable management and supply chain of manure to turn the problem of exceeding nutrients of high-density livestock areas into a resource for the fruit production one. The strategy developed is based on:

- farm scale acidification of animal slurry before mechanical separation to reduce atmospheric emissions of ammonia (NH3) and greenhouse gases (GHG) during storage of solid and liquid separated fractions;
- a proper manure (e.g., solid fraction, digestate) transport chain from the storage basin at livestock farm to the orchard;
- use of innovative technologies for NH3 emission reduction and precise manure application in orchards.

More specifically, a farm scale prototype for automatic acidification of animal slurry with powdery sulphur (S) before mechanical separation was developed and tested. Ammonia and GHG emission during storage of acidified and non-acidified solid and liquid fractions was investigated. The experimental results revealed that the acidification approach based on the use of powdery sulphur has the potential to reduce up to 35% NH3 and up to 20% GHG emissions during storage of liquid and solid fractions, according to manure characteristics and storage conditions.

The use of digestate and acidified solid fraction in fruit orchards is optimized by means of two innovative manure spreaders prototype equipped with a device for band spreading and an electronical system to automatically adjust the nutrients application rate according to the spatial crops' nutrients requirement.

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Challenges for the development of the gas-permeable membrane technology for the recovery of nitrogen from wastewater: the LIFE Green Ammonia Project

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The gas-permeable membrane technology has been recognized as one as the most promising technologyies for the recovery of nitrogen from wastewater. This technology consists of a hydrophobic gas-permeable membrane submerged in wastewater through which an acidic solution (commonly diluted H_2SO_4) is recirculated. By diffusion, the NH_3 passes through the micropores of the membrane and is captured in the acidic solution to form an ammonium salt, which can be used as a fertilizer. In the last years, several works have investigated the performance of this technology for the recovery of nitrogen from wastewater from lab to pilot scale. Specifically, in the LIFE Ammonia Trapping a 5 m^3 prototype was designed, constructed and tested for *in situ* recovery of nitrogen from swine manure and digestate. For the swine manure, the average removal efficiency of total ammonia nitrogen (TAN) was 34.2 ± 14.4% in 7-20 days, 62% of the removed TAN being recovered as an ammonium sulfate solution (Molinuevo-Salces et al., 2020). Similarly, the TAN concentration in digestate was reduced by 34.2% on average. The recovery of TAN in the trapping solution in the form of a $(NH_4)_2SO_4$ solution averaged 55.3% of the removed TAN (Riaño et al., 2021). From the experience gained in the evaluation of this technology at pilot scale, the need of further optimization of the design for improving ammonia recovery while reducing ammonia losses by volatilization was emerged. These challenges are being faced in the LIFE Green Ammonia, with the aim of building a commercial model for ammonia recovery from livestock wastewater at farm level, more ergonomic and adaptable to the needs of the farms. In addition, two strategies will be developed to commercialized the ammonium sulfate produced during the treatment and field assays will be performed to evaluate its efficiency as fertilizer.

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Harnessing Reactive Nitrogen in Integrated Food Production, Bioremediation and Energy Generation Systems

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Nitrogen has been identified as a driver of global food insecurity, therefore proper nitrogen management will be critical to feed a growing global population. Inefficiencies of nitrogen use occur at multiple levels within aquaculture and agricultural production chains, leading to net nitrogen loading in the global nitrogen cycle and threatening the sustainability of the planet in terms of reactive nitrogen (Nr) pollution.

Current technologies to treat nitrogen-rich effluent focus on converting reactive nitrogen to back to its inert form, as nitrogen gas in the atmosphere. However, nitrogen is too valuable to be lost. Rather than looking to promote technologies for permanent removal of nitrogen, novel, innovative approaches are needed that focus on the recovery of valuable resources to pioneer sustainable food production systems and catalyse a new revolution in the nitrogen cycle.

My UKRI Future Leaders Fellowship has the ambitious vision of correcting imbalances in the global nitrogen cycle by working with endogenous microbial communities to secure reactive forms of nitrogen for sustainable feed and food production systems. The overall aim is to develop integrated protein production, bioremediation and energy generation systems to treat nitrogen-rich waste from land-based intensive agriculture and aquaculture systems.

These ecologically-driven systems are designed to harness the synergistic and concerted actions of microbial communities and deposit feeding invertebrates, to upcycle nitrogen-rich waste into alternative protein sources for agro-industry and provide a sustainable source of bioenergy by operating as sediment microbial fuel cells.

These low-tech systems offer a simple, low cost option to diversify production in the agro-industry sector, increase revenue, and reduce environmental impacts in the UK and particularly in lower income tropical countries. Large-scale dissemination and adoption of this technology has the potential to correct imbalances in the global nitrogen cycle and secure food and feed production systems for generations to come.

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Closing the gap: soil greenhouse gas emissions in a Holm oak forest

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Mediterranean sclerophyllous forests of Holm oak (*Quercus ilex*) are representative ecosystems of the Mediterranean region. In some areas, these forests are threatened by atmospheric nitrogen (N) deposition (García-Gómez et al., 2014). To comprehend the effects of this pollutant, it is important to understand and complete the N cycle in the ecosystem, including the input of wet and dry N deposition, the retention and transformation that occurs within the canopy, plant absorption and remobilization, and losses as soil gases emissions or leaching. A Holm oak (*Quercus ilex*) forest close to Madrid has been intensively monitored for one year. Air pollutant gases and particle concentration, wet and dry deposition, meteorology, soil humidity and temperature, plant physiological activity and nutrient content, have been thoroughly measured. In addition, possible exits of N compounds in soil ground water and as soil greenhouse gas emissions were assessed as well. Soil gas emissions of N2O, CH4 and CO2 were measured under the tree canopy (6 plots in total under 3 trees) and in open areas (4 plots), using static chambers (V = 19.3L). Gas samples were taken at midday with a 50 ml syringe at 0, 30 and 60 min after closure of the chamber. The sample were transferred to vials and measured with a Hewlett Packard (HP6890) gas chromatograph equipped with an electron capture detector for N2O and flame ionization for CO2 and CH4 detection. The 3 gases were measured at least one per month increasing the number of samplings after rainfalls events. Soil gas fluxes were calculated based of gas concentration change during the sampling period, considering the temperature inside the chamber and the ratio between chamber volume and soil surface area. Soil samples were taken from the perimeter of the sampling plots for soil water content and organic matter estimation. Preliminary results show N2O fluxes in the range -0.45 to 0.4 mg N-N2O m-2 d-1, with similar values under the canopy and in open areas and with no clear seasonal pattern. Only one of the trees showed a significant annual emission of N2O. Emission fluxes of CH4 were very low, usually representing a sink for this compound. Only at the end of autumn significant emission pulses were detected. Annual emissions of CO2 under the trees were significantly higher than in open areas, particularly in spring with values up to 3000 mg C-CO2 m-2 d-1. Results will be discussed in relation to deposition, meteorology and plant physiology.

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Long-term Trajectories of Soil Nitrogen Surplus Across Europe (1850-2019)

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Worldwide surface waters suffer from the presence of nitrogen (N) compounds causing eutrophication and water quality deterioration. Despite many Europe-wide legislations, we still observe high N levels across many water bodies in Europe. Information on long-term annual soil N surplus is needed to better understand these N levels and inform future management strategies.

The goal of this study is to characterize the spatial and temporal pattern of the N surplus across Europe at different spatial scales (i.e., national, subnational or river basin level). To achieve this goal, we constructed a long-term (1850-2019) annual N soil surface budget for both agricultural and non-agricultural soils across Europe at a 5 arcmin spatial resolution. This dataset combines information at different levels (in particular country and grid level) to construct the different N surplus components using publicly available information (e.g., FAOSTAT, EUROSTAT, published literature and reports). Furthermore, we account for the underlying uncertainties resulting from both input data sources and methodological choices in major components of the N surplus (i.e., fertilizer, manure and N removal rates). We demonstrate the consistency and plausibility of our estimates by comparing them with previous studies.

N surplus provides insights into the trends and spatial distribution of excess N into the soil systems across Europe, highlighting agricultural areas across Central Europe being the hotspot of N surplus. These areas have experienced a drastic change over the last 150 years. For example, N surplus over the EU-28 region exhibited a three-fold increase during 1850-1960 (from 6 ± 0.7 to 20 ± 2.6 kg ha^{-1} yr^{-1}), further increased by nearly two times between 1960-1990 (36 ± 1.4 kg ha^{-1} yr^{-1} in 1990), and then reduced by around 30% during 1990-2019 (28 ± 1.2 kg ha^{-1} yr^{-1} in 2019). We demonstrate the importance of considering the N surplus over non-agricultural soils that amounts up to 30% on average across the European landscapes. Importantly we show that N surplus estimates have large uncertainties, which calls for their explicit consideration in analysis of past N surplus trajectories.

Atmospheric deposition of organic nitrogen (DON and WSON) in Spanish Mediterranean forests

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Atmospheric organic nitrogen (ON) plays a key role in atmospheric chemistry, contributing significantly to N deposition, particle formation and long-range transport of nitrogenous compounds. It is a very heterogeneous fraction, made up of thousands of compounds, with very different characteristics, both in terms of toxicity and bioavailability, which makes it difficult to characterize and complicates the determination of its effects on ecosystems.

Recent studies have shown that Norg is not only a local problem linked to the natural biological cycle, but that it is a global problem, contributing ~30% to global N deposition, although this contribution is highly variable depending on location and time of year.

In this study, dissolved organic nitrogen (DON) and water-soluble organic nitrogen (WSON) were monitored in rainwater and aerosols, respectively, at three sites in Spain; two peri-urban areas located in Madrid and Barcelona and a rural site in Pamplona. Additionally, urea was also measured in order to determine its contribution to the in the total ON fraction in the western Mediterranean forests since several studies have shown that labile compounds such as urea or amino acids can be taken up by leaves and branches in an analogous way to NO_3^- and NH_4^+. Lastly, all these compounds were also determined in dry deposition samples obtained from the washing of live and lyophilized branches at the canopy level to estimate the contribution of dry organic N deposition to total DON.

Results showed that WSON constituted a significant fraction of the total soluble nitrogen in aerosols (23% on average) and the total nitrogen in rainwater (about 42%), with WSON being higher in urban sites and DON in rural sites. Approximately 60% of the WSON in the rural site was due to urea deposition being remarkably lower in the other two sites (10% and 17%). Indeed, the rural site showed a canopy uptake of DON in spring and autumn, showing that organic nitrogen may be a supplementary nutrient for Mediterranean forests. Agricultural activities and pollutants generated in metropolitan areas were identified as the potential anthropogenic sources of DON and WSON at the study sites.

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Nitrous oxide emissions in riparian zones of the SUDOE territory. Static and automatic chambers methodology

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Riparian interface, the ecosystem between rivers and terrestrial systems (including farms), is a key point regarding diffuse pollution as it acts as a buffer for nitrate and ammonium surplus from agricultural activities, retaining, transforming and removing it. This prevents that part of the reactive nitrogen (Nr) compounds reach the waterbodies alleviating its pollution and potential eutrophication. On the other hand, riparian soils can also act as hotspots of greenhouse gas (GHG) emissions in what is called *pollution swapping*. Nitrous oxide (N_2O) is produced from the nitrification and denitrification processes that are amplified with the presence of N surplus, water, and organic carbon (C) compounds. Other GHG such as CH_4 or CO_2 are also boosted by the high C content and the intense microbiological activity that characterize these soils.

In the framework of the European project Interreg *AgroGreen-SUDOE* on-site measurements of GHG fluxes, with both static and automatic chambers, were carried out in two riparian zones of the Tagus basin under Mediterranean climate: one nearby the Sorraia River (Coruche, Portugal); and the other one in Henares River (Madrid, Spain). Our results show complex dynamics and changes in emissions driven by environmental factors such as the proximity to water or C and N content of the soil among others. The use of automatic chambers provided a good picture of what happens throughout the day in a specific point, thus allowing to identify hot-moments of fluxes and other factors than can affect the emissions.

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Impact of agricultural management changes on the risk for habitat conservation in protected areas in Spain

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Agricultural activities emit nitrogen (N) compounds to the atmosphere (mainly ammonia) that are eventually deposited on terrestrial and aquatic ecosystems. Previous risk-assessment studies alerted of the risk of eutrophication effects related to N deposition in protected areas. In the present work, we investigate the potential to mitigate these impacts by reducing agricultural ammonia emissions in Spain. Spain was selected for this exercise because there is a strong knowledge base on its food system and there are previous works on the threat that atmospheric N deposition represents to biodiversity conservation in this country.

Scenarios of ammonia emissions mitigation developed in the framework of the AgroGreen-SUDOE project will be compared to business-as-usual scenarios, and used to model the atmospheric transport and chemistry of N pollutants with the CHIMERE model. Total N deposition from this modelling exercise will be used to assess the risk of N-related effects on protected habitats within the Natura 2000 network. The risk assessment will be performed, following the Air Convention methodologies (CLRTAP-UNECE), by spatially explicitly mapping the exceedances of the empirical critical loads of N for the different protected habitats. The risk assessment results using the different scenarios of ammonia emissions will be discussed in comparison with previous results (García-Gómez et al., 2014), with special focus on the most threatened habitats by N deposition, such as natural grasslands and other mountain habitats (including as medium- and high-altitude scrublands and heathlands and mountain forests of *Pinus uncinata*, *Abies pinsapo* and *Quercus ilex*). The results of this study will be of importance for policy makers and society, since they points to biodiversity conservation attributes of emission control that are usually unnoticed in agricultural studies.

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Development of new fertilizers based on urea coated with biopolymers and biostimulants: CALL FOR PARTNERS

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The agricultural world, which must meet the challenges of a growing demand for quantity and quality of food production, is today faced with the difficulties of a nitrogen fertilizer market impacted by a geopolitical context which shows the fragility of the supply chains, but also by serious environmental issues (water pollution, GHG emissions, etc.). As part of this change, the new European regulation on fertilizers (RCE 2019/1009 coming into force in June 2022), part of the circular economy, lays the foundations for virtuous practices and in particular the use of products of organic origin and a minimal impact on the grounds. Urea is a concentrated and inexpensive mineral nitrogen fertilizer, which makes it difficult to replace. However, a major problem with urea is the loss by volatilization of ammoniacal nitrogen after its application on the field. Several technologies can be implemented to protect this urea and thus reduce its environmental impact by improving its efficiency.

Our objective in the European SYNERG'N project is to explore a new way of formulating urea fertilizers in combination with plant biostimulants in order to improve the slow and gradual release (biopolymers) and the nitrogen use efficiency and biopolymer to reduce ammonia volatilization.

This The formulations (compounds) developed within the framework of this project will have to take into account the balance between different factors: the nitrogen content of the coated fertilizer, the benefits for the crops, compliance with environmental requirements and profitability. economic. Their technical assessment will be carried out within the framework of European regulations (RCE 2019/1009): Specifications (mechanical resistance, attrition, solubilization) of coated fertilizers ; Measurement of the kinetics of biodegradability and release of nitrogen in the soil (available for the plant) ; Measurement of nitrogen losses by volatilization of ammoniacal nitrogen after spreading ; Improved nitrogen use efficiency by crops

The project is currently in its exploratory phase for 1 year. It is led by RITTMO agroenvironment (actor in the regulation and demonstration of the efficacy of fertilizing materials) and involves other partners specialized in materials, processes and polymers. First results are encouraging and we are looking for partners to set up a project at European level.

FOLIAR NITROGEN UPTAKE IN A MEDITERRANEAN FOREST: A FERTILIZATION EXPERIMENT WITH LABELED NITROGEN

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Atmospheric nitrogen (N) deposition exceeds the empirical critical loads established for the conservation of some ecosystems in Spain. Previous risk studies have identified Mediterranean sclerophyllous forests of Holm oak (*Quercus ilex*) as one of the ecosystems threaten by atmospheric N deposition (García-Gómez et al. 2014). Studying and analysing all the forest nitrogen-cycle processes is essential to understand the potential effect of N deposition in these ecosystems. Nitrogen retention and uptake by the canopy is an important part of this cycle.
Calculating the rates and variations in the uptake of oxidized and reduced N compounds is important for improving nitrogen balance models. To estimate foliar N retention and possible seasonal changes in the retention rates in a Holm oak forest, a short-term fertilisation experiment with labelled ammonium (15N-NH4) and nitrate (15N-NO3) were performed seasonally. Fertilizing solutions were prepared to simulate conditions of low and high N deposition, based on deposition data reported from previous studies (García-Gómez et al. 2018). Ten branches in six trees were marked and prewashed before fertilisation. Once dry, 2 branches per tree were thoroughly sprayed with 5 different treatments: control, low and high NH4, low and high NO3. Branches were collected 1 hour after the fertilisation and brought to the lab for immediate processing. Branches were rinsed with deionized water to remove nutrients retained on plant surfaces and current and one-year leaves were separated before grinding for isotope analyses.
In addition to fertilisation, ecophysiological and meteorological measurements were taken to investigate the possible relationships between uptake rates, plant activity and meteorological conditions. The results showed that Holm oak leaves were able to absorb both oxidised and reduced N compounds, with higher rates of NH4 absorption. Moreover, the absorption rate of compounds were leaf-age dependent and different among season, but no clear relationship with plant activity was found.

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N cycling in food/excretion systems: the potential of human excretions used as fertilizers

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Nitrogen (N) in human excretions (urine and feces) is currently treated as a waste and a source of pollution. For the past decades, in the cities of the global North, the adopted solution has been to neutralize nitrogen in wastewater treatment plants (WWTP), especially through denitrification, and to release it in its inert form (N_2) in the atmosphere. Yet from a nutrient cycling viewpoint, this is a loss of a valuable resource, especially in a context where N fertilizers are currently obtained through the Haber-Bosch process.

Using operational data, we show that N abatement rate in French WWTP increased in the 2000s but has stagnated since the 2010s, releasing about 1/3 of the incoming pollution in the waters. Only about 10% is recycled as fertilizers in the form of sludge spread on crops. The remaining N is mostly denitrified.

Yet human nitrogen was broadly recycled in agriculture in the end of the XIXth century in France (Barles, 2005) and numerous techniques are currently being (re-)developed and (re-)implemented to use human nitrogen in agriculture, especially through source separation of human excreta (Legrand et al., 2021). To explore the regional potential of more circular systems in France, we also assess the spatial distribution of N present in human excretions and compare it to animal manure. For most regions human excretions represent 20%-60% of livestock excretion spread on crops. Yet for 2 French regions, the human potential is higher than manure, especially in the Paris area where it is 25 times higher.

This quantification of the N potential of human excretions used as fertilizers would be especially useful for scenarios assessing a drop in livestock numbers, resulting in a decrease in manure availability.

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The fate of nitrogen in the urban area – the case of Zielona Góra, Poland

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The anthropogenic change of the nitrogen cycle is strongly triggered by urban demand (food and meet consumption, energy demand, transport), and impacts to human health (water pollution or air pollution) concentrate on cities, a consequence of high population densities. Thus, an urban perspective on a predominantly rural pollution becomes relevant. Urban N budgets may be considered less intrinsically connected, so that separation of an agro-food chain and a industry-combustion chain is warranted (Winiwarter et al., 2020). Results have been obtained for Zielona Góra, Poland, a city of 140,000 inhabitants characterized by domestic and transport sources and forest-dominated surroundings. Nitrogen flows are largest along the agro-food chain. In addition to food imports, fertilizer imports also account for a significant share, at 39%. Most of the agro-food N (45 %) is denitrified in wastewater treatment. N associated with combustion (mainly NOx emissions from vehicles) represents a much smaller share, amounting to 22% of the N entering the agri-food system. This overall picture is maintained also when specifically addressing the city center, with the exception of mineral fertilizer that plays a significantly smaller role (7%) in relation to fertilizers introduced in the city. These results have been discussed with local stakeholders.

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The impact of riparian buffers on N loading in the Nooksack River transboundary watershed

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Nutrient pollution and the resulting eutrophication of coastal waters are a growing concern in the Salish Sea, along the Pacific coast of Washington State and British Columbia. Here, seasonal hypoxia harms marine food webs, threatens already-impacted salmon populations, and interferes with tribal fishing rights. The Puget Sound Nutrient Source Reduction Project concluded that communities need to reduce nitrogen loads from both wastewater treatment plants and river inputs to meet water quality standards for dissolved oxygen. The restoration of riparian habitat buffers along waterways can mitigate nutrient pollution in watersheds. However, the effectiveness of these buffers for nutrient reduction varies, depending on several biophysical factors, such as the nutrient loads from upland sources and hydrological flow paths. In light of this variability, this study uses watershed modeling to quantify the ecosystem service of nutrient retention in natural and restored riparian buffers in the transboundary (U.S. and Canada) Nooksack River watershed. To quantify N retention in riparian buffers, we first quantified natural and restored riparian buffers using LIDAR data. We then fit the InVEST Nutrient Delivery Ratio (NDR) model to simulate N flux in the Nooksack River watershed. We refined our input data using crop cover and recommended nutrient inputs for fertilization and manure application from local extension agencies. We calibrated the model across multiple subwatersheds for the years 2013 to 2017 against annual nitrogen fluxes estimated using monthly sampling and the Load ESTimator model (LOADEST) developed by the U.S. Geological Survey.

For the years 2013 to 2017, LOADEST estimated a median N export of 2,553 tonnes N yr^{-1} for the whole Nooksack River watershed, 725 tonnes N yr^{-1} for the upper watershed, and a range of 2 to 344 tonnes N yr^{-1} in the lowland subwatersheds. The NDR model captured the major variation in N export among subwatersheds of different sizes, but did not capture the yearly variation within each subwatershed. Initial parameters derived from the literature underestimated N flux by 3-to-29-fold across subwatersheds. We tested NDR's sensitivity to changes in three key parameters. Threshold Flow Accumulation (TFA) reflects the density of the stream network in a watershed. We tested values 2,000 and 1,000 pixels, a range determined by comparing model outputs to an existing stream layer. Lowering the TFA from 2,000 to 1,000 more accurately captured the prevalence of small waterways, like agricultural ditches, and resulted in a 5% increase in N export. The Critical Length is the distance dissolved nutrients need to travel to reach the maximum retention achieved by each land-use type. We increased the Critical Length from 10 m to 50 m and then to 250 m, which increased N export by 3.5% and 15%, respectively. The Borselli K (K) parameter controls the shape of the relationship between hydrological connectivity and the proportion of nutrients from a given pixel reaching a waterway. Increasing K from the default value of 2 to 8 created a more linear relationship, which resulted in a 29% increase in N export. It took high hydrological connectivity and unrealistically low nutrient retention efficiency of both natural vegetation and crops for modeled values to match LOADEST data. Our initial results suggest that effectively reducing N loading from the Nooksack River watershed will require a combination of management practices, in addition to riparian restoration. In future work, we will use the LIDAR-identified riparian buffers and the calibrated NDR model to estimate the quantity of N retained by buffers in the watershed. We will then run the calibrated model with key restoration scenarios to explore the extent of nutrient reduction possible from restoring additional riparian habitat. The fitted NDR model can demonstrate the scope of restoration needed at the watershed scale to help achieve different levels of water quality benefits in Puget Sound.

Root traits explain multitrophic interactions of soil microfauna on N mineralization and plant growth

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Plant productivity highly depends on soil N mineralization and the subsequent acquisition and utilization by plant, involving intense interactions between roots, microorganisms and animals. Both herbivorous and bacterivorous microfauna have been proven to strongly influence root traits, soil N mineralization, and plant growth. However, their interactions and combined effects are poorly known as our knowledge is mainly based on isolated studies of one of these organism groups. This study investigated how herbivorous nematodes (*Pratylenchus zeae*), bacterivorous protists (*Acanthamoeba castellanii*), bacterivorous nematodes (*Rhabditis oxycera*), separately and in combination, affect root traits, soil N mineralization and plant growth. The experiment was conducted Italian ryegrass (*Lolium multiflorum*) cultivated in individual specially designed sterile plant-soil-air microcosms. Our results show that bacterivorous nematodes increased total plant biomass predominantly via enhanced soil N mineralization, while herbivorous nematodes decreased total plant biomass through direct consumption of root biomass and reduced soil N mineralization. Negative interaction between herbivorous and bacterivorous nematodes on plant growth were detected, which are mainly explained by high root nitrogen concentration and low root tissue density along the second dimension of root economic space, and additionally due to reduced N mineralization. Bacterivorous protists and related interactions showed negligible effect on both plant growth, root traits and soil N mineralization, which might be the consequence of unsuccessful colonization. In sum, our study showed the negative multitrophic interactions between soil herbivorous and bacterivorous microfauna on plant growth in the context of heavily herbivorous nematodes infection. Notably, this study advanced our understanding of the multiple pathways of how soil herbivorous and bacterivorous microfauna, separately and in combination, affect plant growth via influencing root traits and/or soil N mineralization.

Nitrogen availability and losses from digestates, organic and mineral fertilizers

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Nitrogen fertilizers are commonly used to support crop production. The European commission requires a reduction of non-renewable resource for fertilizer production and promotes waste valorization. Organic form of nitrogen becomes an important resource for agriculture. A study was carried out during three years to evaluate the efficiency of three organic fertilizers (solid and liquid digestates, chicken manure) and two mineral fertilizer (urea and ammonitrate).

Study was implemented at the laboratory scale and in lysimeters to evaluate losses of nitrogen by ammonia volatilization, nitrogen leachates and nitrogen uptake. Fertilizers were applied between 65 Kg N.ha-1 and 114 Kg N.ha-1. At laboratory scale, nitrogen mineralization was measured according to European standard by incubation for 3 months. Ammonia volatilization was evaluated with a chamber method: soils were placed in glass chambers with air circulation and ammonia was trapped in sulfuric solution for 14 days. Ryegrass trials in 0,125 m^2 lysimeters were carried outdoor. Nitrogen leachates were measured after 30 mm stormy rain episodes. Ryegrass were collected three times to measure crop production and nitrogen uptake.

Ammoniacal-nitrogen in liquid digestate was 66 % higher than chicken manure (10 %). Ammonia volatilization ranged from 0 % to more than 36 % of the total applied nitrogen with highest values observed for urea fertilizer. Expressed in percentage of the total applied nitrogen, leachates ranged from 5 % for chicken manure to more than 30 % for ammonitrate fertilizer. Ryegrass production measured in ammonia-fertilized lysimeters was significantly higher than in other treatments.

Principal component analysis using ammonia volatilization, nitrogen availability and leachates was performed to summarize all experiments. It showed 3 groups. The first group included both mineral fertilizers and liquid digestate. The second group contains organic fertilizers whereas the third group contains solid digestate.

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Results from a novel woodchips bioreactor test center may improve the performance of field-based woodchips bioreactors

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Agricultural production is a major source of diffuse pollution, which in Europe, mostly is due to excessive emissions of nutrients (nitrogen (N) and phosphorus (P)). N removal from agricultural drainage water in woodchips bioreactors is relatively well established, however, Addy et al. (2016) concluded in a meta-analysis, that more field-based studies of the performance of woodchip bioreactors are needed to determine removal rates in different landscapes, nitrate loading, and climate. Hence, the main objectives of the present study were to i) present results on N and phosphorus (P) removal in five field-based woodchips bioreactor facilities receiving agricultural drainage water and located in different geo-regions in Denmark and ii) to present the results of a cost-effectiveness analysis iii) further, to assess from experiments in a novel woodchip bioreactor test center at which hydraulic residence time (HRT) with winter cold water resulted in the most efficient N removal. Two years data from the five field based bioreactors showed N removal rates varying from 1.49 to 5.37 g N m^{-3} d^{-1} and a mean across all bioreactors and years of 2.90 g N m^{-3} d^{-1}. The loss of phosphorus was relatively high the first year after establishment varying at rates from 298.4 to 890.8 mg P m^{-3} d^{-1}. However, in the second year most bioreactors retained phosphorus at rates varying from 12.2 to 77.2 mg P m^{-3} d^{-1}. The investments and the costs of the bioreactors were larger than expected based on the standard investments for bioreactors used in Denmark. The cost efficiency analysis pointed to larger investments in the bioreactor itself as well as more advisory costs as key issues. The N removal cost for the four bioreactors considered in this study was around 350 DKK per kg N (€47 per kg N) which is higher (+50%) than the standard cost per kg N used by Danish authorities. From several investigations in a novel woodchips bioreactor test center with a water temperature of 5 °C and an inlet concentration of 60 mg nitrate per liter, the maximal nitrate reduction rate was found at HRTs of 20-30 h. Further studies needs to be done under controlled environments to assess the most efficient design of woodchip bioreactors under varying drainage water temperatures and flows, and as well how to retain the initial release of phosphorus.

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Understanding the inconsistency in performance of nitrification inhibitors by exploring their interactions in soil.

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When nitrogen (N) fertiliser is applied to soil, a large proportion can be lost to the surrounding environment. The N waste associated with fertilisation is often reported to exceed 50 %. These losses represent a significant inefficiency in food production systems and can manifest in negative environmental outcomes (e.g. nitrous oxide emissions, eutrophication of waterways, groundwater contamination, etc.). Nitrification inhibitors (NI) have been shown to reduce N waste (Yang et al. 2016) and could become an invaluable means of increasing N use efficiency in high input agricultural systems. Over the past 50 years, NIs have been used in different agricultural settings worldwide. However, their efficacy is highly variable in different soils. Some key soil properties have been negatively correlated to NI performance, such as clay and organic carbon % (Guardia et al. 2018). As general indicators, these properties do not accurately predict the efficacy of NIs. It is unknown whether the inability to predict the impact of NIs on nitrification using soil properties is due to (a) an insufficient characterisation of the soil environment; or (b) a lack of information on how these properties regulate NI bioactivity and therefore efficacy. Understanding how NI behave in soil may allow more successful utilisation of NIs in agricultural systems. Furthermore, understanding how interactions with soil exert a negative influence on the efficacy of NI may provide useful insights for the development of more effective NIs. This talk will discuss the implications of recent research into the interactions between soil and the NI 3,4-dimethylpyrazole phosphate (DMPP).

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Productivity improvements of rubber with application of different sources of fertilizers

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Hevea brasiliensis is one of the major perennial plantation crops grown in Sri Lanka. The latex yield of rubber is influenced mainly by the type of clone, fertility status of the site and the management measures used. Since the land productivity has been depleted, nutrient management in rubber plantations using site specific, controlled, slow releasing fertilizers and use of strait fertilizers have gained greater importance in recent years to improve nutrient use efficiency and to reduce cost of production while increasing the productivity. This experiment was carried to assess growth and yield performance of rubber in wet zone of Sri Lanka under different sources of fertilizer application. Suitable plots representing 1, 3 and 5 years old young rubber plants and 7-year-old tapping trees from RRIC 121 clones and three girth categories of 55cm, 55-65 cm and above 65 cm at 160 cm from bud union were selected for this experiment using five different fertilizer treatments, namely; conventional fertilizer mixture (12-14-14), granular mixtures 1 (12-11-18), granular mixtures 2 (14-14-21), and control released which provided 50% equivalent of the conventional. The dry rubber content of 7 years old rubber field and latex volume was significantly different ($p<0.05$) among the fertilizer treatment and granular fertilizer-2 had the highest dry rubber content 25.9 g per tree and 71 ml per tree. Also Agronomic Nitrogen Use Efficiency (ANUE) was highest in the granular fertilizer-2 which was 3.73. Highest stem girth growth (10.8[a] cm) of one-year-old rubber field was observed in granular fertilizer-1 applied plot while highest stem girth of three-year-old rubber field (27.8 cm) was observed in granular fertilizer-2 applied plot. However, stem girth growth of five-year-old rubber was highest (41.2 cm) in conventionally fertilizer applied treatments.

The humic-acid activation of nutrient transporters in the root is mainly regulated by jasmonic acid and indoleacetic acid.

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Previous studies carried out in our laboratory showed that the shoot growth promoting effect of rhizospheric humic-DOM is directly linked to the root to shoot cytokinin translocation associated with nitrate root uptake and further translocation (Mora et al., 2010). This ability of humic-DOM was also linked to the upregulation of the main nitrate transporters in root as well as PM-root ATPase and other nutrient transporters. However the signaling pathways involved in the regulation of this effect of humic-DOM on nutrient transporters are unknown.

In this context we have investigated this signaling process through the study of the effect of a sedimentary humic acid (HA) as a humic-DOM model on the growth, hormonal balance and nutrient transporters gene expression of several Arabidopsis mutants affected in the signaling pathways of the main phytoregulators involved in the action of HA on plant growth and mineral nutrition.

The results showed that jasmonic acid is the main phytoregulator that regulates the upregulation of nitrate transporters by HA, while root PM ATPase and iron related genes FIT and FRO2 were regulated through auxin signaling pathways.

Nitrate signal use as potential modulator of plant metabolism in ammonium-fed crops

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Ammonium nutrition triggers physiological and metabolic disorders in plants which are mainly evidenced as biomass reduction. The origin of ammonium (NH_4^+) toxicity is attributed, among others, to an excess of this cation in the cell. Plants response to ammonium accumulation by increasing glycolic flux and thus, C skeletons for NH_4^+ incorporation to amino acids. The application of nitrate (NO_3^-), including concentrations in µM range that do not represent a nitrogen (N) source, produces a relief effect on ammonium-fed plants which ultimately translates into yield improvement. Even though our results suggest that nitrate signal strongly modulates the glycolic and Calvin-Benson pathways, the metabolic action mechanism underlaying its positive effect is still unknown. Here, we present the main results of carbon metabolism modulation obtained in our laboratory. These results may shed light on some important aspects of N nutrition management in soilless culture systems to improve NH_4^+ use efficiency.

Ntrace, an advanced tool for analysing ^{15}N tracing data

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Ntrace is a tool to quantify simultaneously occurring gross nitrogen (N) transformation rates. Since the original publication of *Ntrace* in 2007, a family of tools has been developed to cover a range of applications such as plant uptake, nitrite and gaseous N dynamics. While the tool has been extended to cover this range of applications, the underlying optimisation algorithm has remained unchanged. This parameter optimisation was originally based on the Metropolis MCMC algorithm. However, especially with the more computational demanding applications, this was very time consuming, and was not always able to find an unambiguous parameter set. Here we will present an updated *Ntrace* tool that utilises Matlab's GlobalSearch as its new global optimisation algorithm. Based on the re-evaluation of some already published datasets, this new algorithm turned out to be not only much faster than the original algorithm, but also yielded a better fit to the measured data. The updated tool also includes a new parameter uncertainty calculation, based on the Levenberg-Marquardt method, and does therefore not rely on well-defined probability density functions anymore. Furthermore, an option to optimise the initial pool sizes has been included, which is useful when measurements are not taken immediately after ^{15}N addition. Overall, the updated *Ntrace* tool is faster in finding a suitable parameter set and thus determining gross N transformations. Furthermore, the fit to measured data is generally improved. We would therefore recommend the use of this updated *Ntrace* tool for analysing ^{15}N tracing data.

Impact of missing inputs and outputs in agri-environmental N indicators

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Nitrogen (N) pollution is tackled in agri-environmental indicators using two main indicators, the gross nitrogen balance (GNB) and the N use efficiency (NUE). Both are calculated by tracking all the total N inputs and outputs in cropping systems, which usually rely on data availability and relevance at the national scale. This simplified approach fails to include other inputs and outputs that are missing from agri-environmental indicators. We focused on six missing N flows: irrigation, mineralization (net mineralization and net sequestration), crop residues (left and removed from the field) and non-symbiotic N fixation. Here, we compiled a dataset of 1078 data points from 116 studies that quantified the GNB and/or the NUE, across 26 countries. We show that the omission of these missing terms yielded statistically significant differences in both indicators, except for the non-symbiotic N fixation. Irrigation and net sequestration were the input and output with the largest influence on the GNB (87 ± 494 and -43 ± 44.3 kg N ha^{-1} yr^{-1}) and NUE (-38 ± 494 and 56 ± 65%), respectively. Our data suggests that agri-environmental studies are likely under- and overestimating the real extent of N pollution and N use efficiency by not including missing inputs and outputs, respectively. We highlight the main knowledge and data gaps, and the path forward for a better inclusion of the missing inputs and outputs in agri-environmental indicators.

Identification of Rice Genotypes with Efficient Nitrogen Use by Assessing Phenotyping and Molecular Traits

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Nitrogen is quantitatively the most important nutrient input for rice. However, the inefficient use of nitrogen fertilizers can be harmful to the environment. Over the years, when rice varieties bred with greater yield potential, input use efficiency has not been given high priority aiming at optimizing nutrient absorption. Breeding rice cultivars with improved nitrogen use efficiency (NUE) is becoming an important criterion for lowering production costs and reducing environmental pollution. It is essential to understand the underlying genetic mechanisms controlling efficient use of nutrients and traits associate with the NUE. However, little efforts have been made to identify varieties with higher NUE, traits and related genes on this aspect. Therefore, this research work has been designed to identify the level of NUE in gemplsms, responsible genes and their level of expression and morphological features associated with varieties having higher NUE. Initial field level varietal screening experiments was conducted at the Rice Research and Development Institute, Batalagoda (RRDI, Bg) (7.5324^{0}N, 80.4340^{0}E), Sri Lanka, which comes under low country (<300 m) intermediate zone (1750-2250 mm annual rain fall). Forty (40) locally cultivated rice varieties were assessed under no nitrogen (only the residual N of 0.8%) vs 225 kg/ha urea (Department of Agriculture recommendation) to identify high NUE varieties and to study the expression of related genes through transcriptome analysis and the heritability pattern of NUE of selected rice genotypes. The experiment was carried out during *Maha* season (October to February) 2021/22 under irrigated conditions. Among the tested varieties At 362 and Bg 366 gave higher NUE among tested new improved rice varieties and Gonabaru and Godaheenati among the tested traditional rice varieties. Traditional variety Suduheenati was identified as one of the best performing variety (3.86 t/ha) under no N and it was identified as the lowest NUE among all the tested rice varieties.

Key Words: New Improved Rice varieties, Traditional Rice Varieties, Urea, Nitrogen Use Efficiency

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Crop development controls denitrification through Carbon exudation, Nitrogen and water uptake

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Denitrification is the main source of the greenhouse gas N_2O emitted from agricultural soils. While N_2O emissions and influencing factors have been very well studied in field experiments, there are hardly any reliable data for N_2 emissions on the field scale. However, these are essential to understand under which conditions complete denitrification occurs leading to N_2 formation and when N_2O is the main end product. Whether NO_3^- is reduced to N_2O or N_2 depends on several factors: the availability of NO_3^- and available organic C, as well as pH, oxygen availability, soil moisture, denitrifier community structure, and temperature. All of these parameters are highly dependent on crop development, as growing plants take up NO_3^- and water while increasing organic C availability via root exudates and dying roots, and alter soil pH as well as microbial communities by rhizosphere dynamics.

The objective of this field trial was to collect reliable measurement data on N_2 and N_2O fluxes in typical German crops. Two crops were chosen that differ greatly in their temporal development: Winter wheat (*Triticum aestivum* L.) and sugar beet (*Beta vulgaris* subsp. *vulgaris*). Both crops were grown site-typically according to the rules of good agricultural practice. To measure N_2O and N_2 emissions, the improved ^{15}N gas flux method including high enrichment ^{15}N-labeled fertilizer was applied. Prior to gas sampling, chambers were purged with a mixture of helium and oxygen (80:20) to reduce the atmospheric N_2 background to < 2%. Soil samples were taken at regular intervals and analyzed for mineral N (NO_3^- and NH_4^+) and water-soluble Corg content. In addition, we monitored crop development, plant N uptake, N transformation processes in soil, and N translocation to deeper soil layers.

Both crops strongly differed in plant growth and N uptake throughout the growing season controlling both N and C availability in soil. Accordingly, N_2O and N_2 emission patterns differed between crop species. Overall, emissions were highest when plant N uptake was low, i.e., during early growth stages, ripening, and after harvest. Incorporation of sugar beet leaves after harvest led to a strong increase in N_2O emissions, which was not directly reflected in N_2 fluxes. Within one species, soil moisture and temperature were main controls of N_2O+N_2 losses.

In summary, we observed similar patterns in N_2O and N_2O+N_2 emissions. Differences in crop development and crop management were clearly reflected in total N_2O+N_2 losses and the $N_2O/(N_2O+N_2)$ ratio.

A global synthesis of soil denitrification: driving factors and mitigation strategies

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Dinitrogen (N_2) and nitrous oxide (N_2O) produced via denitrification may represent major nitrogen (N) loss in terrestrial ecosystems. A global assessment of soil denitrification rate, $N_2O/(N_2O+N_2)$ ratio, and their driving factors and mitigation strategies is lacking. We conducted a global synthesis using 225 studies (3367 observations) to fill this knowledge gap. We found that daily N loss through soil denitrification varied with ecosystems and averaged 0.25 kg N ha^{-1}. The average emission factor of denitrification (EF_D) was 4.8%. The average $N_2O/(N_2O+N_2)$ ratio from soil denitrification was 0.33. Soil denitrification rate was positively related to soil water-filled pore space (WFPS) ($p<0.01$), nitrate (NO_3^-) content ($p<0.05$) and soil temperature ($p<0.01$), and decreased with higher soil oxygen content ($p<0.01$). N_2 emissions increased with latitude ($p<0.05$), WFPS ($p<0.01$) and soil mineral N ($p<0.05$) but decreased with soil oxygen content ($p<0.05$). The $N_2O/(N_2O+N_2)$ ratio increased with soil oxygen content ($p<0.01$) but decreased with organic carbon (C) ($p<0.05$), C/N ratio ($p<0.01$), soil pH ($p<0.05$) and WFPS ($p<0.01$). We also found that optimizing N application rates, using ammonium-based fertilizers compared to nitrate-based fertilizers, biochar amendment, and application of nitrification inhibitors could effectively reduce soil denitrification rate and associated N_2 emissions. These findings highlight that N loss via soil denitrification and N_2 emissions cannot be neglected, and that mitigation strategies should be adopted to reduce N loss and improve N use efficiency. Our study presents a comprehensive data synthesis for large-scale estimations of denitrification and the refinement of relevant parameters used in the submodels of denitrification in process-based models.

Nitrogen immobilisation, mineralisation, and uptake of silage maize and sugar beet following cover crops from different functional groups

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Cover crops (CC) are known for their mutual benefits like preventing nitrogen (N) leaching losses or soil erosion as well as enhancing soil functioning or biodiversity. However, positive effects on N uptake and yield of the following cash crop are less evident. The impact of CC on subsequent cash crop growth and N utilisation strongly depends on their C/N ratio which varies widely between species. Therefore, we set up a replicated field trial with four winter CC from different functional groups followed by N level experiments with silage maize (SM) or sugar beet (SB) to evaluate their effects on plant-soil N dynamics compared to a bare fallow control in two consecutive years at four sites across Germany. CC were three non-winter hardy species (oilseed radish (*Brassicaceae*), saia oat (*Poaceae*), spring vetch (*Leguminosae*)) and winter hardy rye (*Poaceae*).

Our results showed successful CC canopy developments with variations from 6 to 50 dt ha^{-1} (SM) and 22 to 40 dt ha^{-1} (SB) dry matter (DM) across species and site-years. This resulted in maximal N uptake by CC biomass of 16 to 79 kg N ha^{-1} (SM-sites) and 41 to 172 kg N ha^{-1} (SB-sites), with highest potential by radish and rye and lowest by vetch. Soil mineral N (0-90 cm) was significantly reduced during winter under all CC (rye>oat>radish>vetch). C/N ratios of CC ranged from 10.4 to 27.0 (SM) and from 9.0 to 17.1 (SB) in the order vetch<radish<rye<saia oat with impacts on further N dynamics. N uptake of the subsequent SM was significantly increased without added N by 37 kg N ha^{-1} compared to bare fallow (vetch>radish, not significant for rye>oat), but with optimal N fertilisation no advantages of CC were observed. For unfertilised SB, even lower N uptake was observed (CC<fallow). Effective N mineralisation in SM was significantly higher by 44 kg ha^{-1} following CC without N fertilisation and increased by 27 kg ha^{-1} only with added N (not significant). CC seemed to tendentially increase already high fertiliser N immobilisation rates in SM of on average 34 % by another 13 % compared to bare fallow (vetch>rye>radish, no effect for oat). Maize DM yield (146.5/162.2 dt ha^{-1} without/with N) did not significantly differ between CC and fallow treatments. In unfertilised SB no significant advantages of net mineralisation after CC were observed and in 1 out of 4 site-years sugar yield was even significantly lower after radish and rye.

In summary, there was a trade-off between N buffering during winter (main driver CC biomass) and N supply and utilisation of the subsequent cash crop (main driver C/N ratio of CC residues) with radish turned out to show the most net benefits for SM cropping systems without yield effects and rather negative tendencies of CC on SB sugar yield.

Abiotic nitrogen cycle in agricultural soils: NOx fixation/emission through photocatalytic reactions

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The nitrogen (N) cycle has been intensively studied for more than a century. Biological reactions in soils are mediated by microorganisms and release nitrogen oxides (NO and NO_2) and greenhouse gases (N_2O) to the atmosphere. Nitrogen oxides (NOx) have a negative effect on human health and air quality, i.e., tropospheric ozone (O_3) production, and N_2O (with a global warming potential around 300 times larger than carbon dioxide, CO_2).

Although the contribution of abiotic reactions to the N cycle in aquatic ecosystems and in the atmosphere (aerosols) is well-known, little attention has been paid to abiotic reactions of the N cycle in agricultural soils (Doane 2017). In soils, abiotic photocatalytic reactions of NO to nitrate (NO_3^-) require an UV-visible irradiation as energy source and semiconductor materials that act as catalysts, such as Ti, Fe and Zn oxides, water and oxygen. These reactions were recently investigated from a limited range of soils with different physical and chemical properties (Barrón et al. 2020). Building on this previous study we have (i) assessed the occurrence of photocatalytic reactions across a global range of agricultural soils (cambisols, calcisol, luvisols, acrisols, vertisols and ferralsols), and (ii) determined the contribution of key soil and environmental factors to these reactions. Laboratory experiments have shown that soil mineralogy is key for these abiotic reactions. Highly weathered soils rich in Ti, Fe and Al oxyhydroxides were able to fix a considerable amount of ambient NOx gas in forms of NO_3^-, that are plant available; especially under high UV-visible intensity. However, high concentrations of soil organic matter and inorganic N, could lead to the emission of NOx also from photocatalytic reactions. We conclude that the balance of these abiotic reactions should be considered alongside more traditionally studied N cycling processes when considering improved strategies for sustainable agriculture, especially if abiotic N fixation is shown to be a significant input of N in some agricultural systems.

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Agro-physiology of grasses and legumes destined for biorefining of protein – effects of defoliation and fertilization regimes

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Perennial herbaceous plants after defoliation follow one or a combination of two 'reserve dependent' regrowth strategies, to either photosynthesise with remaining leaves or halt root growth and remobilize stored assimilate when defoliation is severe (Wang et al., 2021). Their productivity thus integrates photosynthesis, soil nitrogen (N) uptake and internal remobilization, but remain poorly understood for different species subjected to fertilizer and defoliation regimes and targeting biorefining of feed protein. Field experiment was conducted from 2019 to 2021 on sandy soil in Denmark with either fertilized grasses (perennial ryegrass, tall fescue), unfertilized legumes (alfalfa, red clover) or their fertilized mixture (grass-legume), each defoliated in high (2), medium (4) or low frequency (6 weeks) at either 7-9 or 12-14 cm height. Differences between treatment means (excluding the establishment year 2019) were evaluated by mixed-effects model fitted to annual biomass and N yield. Grass species, defoliation frequency and height were highly significant factors for both biomass and N yield, whereas N fertilization as influential factor was likely offset by the unfertilized legumes, prompting for data analysis method integrating multiple two-way interactions as more suitable. The largest biomass was obtained by tall fescue (11.8-14.2 Mg ha-1) and grass-legume mixture (12.5-13.3 Mg ha-1), both defoliated at medium to low frequency, regardless of N fertilization and defoliation height. For N yield, the systems with red clover (395-440 kg N ha-1) and grass-clover mixture (360-400 kg N ha-1) defoliated at high to medium frequency were significantly more productive than the others. Within the season, the results clearly showed the contribution of the spring and main-season defoliation event to the annual biomass (Zhang et al., 2021). We also estimated canopy radiation use efficiency and measured extractable protein to elucidate to which extend it reflects the N yield and thus support the integration of environmental and economic sustainability of perennial systems targeting biorefining of feed protein. This study also provides novel insights in perennial productivity modulated in dynamic terms by management.

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Soil nitrogen enrichment using biomass of *Gliricidia sepium* injected with labelled ^{15}n fertilizer and subsequent recovery by *Zea mays*

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Alley-cropping agroforestry has been identified as a sustainable land use system for degraded lands in the humid tropics. Therefore, nutrient dynamics and soil improvement potentials of alley cropping system in situations where land degradation is high need detailed investigation. This study was initiated to assess and quantify nitrogen dynamics in a Gliricidia-maize alley-cropping by enriching soil nitrogen using biomass of *Gliricidia sepium* injected with labelled ^{15}N fertilizer and subsequent recovery by *Zea mays* in an alley cropping system. The experiment was conducted at the experimental farm of the University of Peradeniya, Sri Lanka. Three-year-old isolated Gliricidia trees (trenched around each tree with 2m radius) were injected with 98% ^{15}N-enriched Ammonium sulphate (1.415g/tree) and harvested four weeks after injection. Harvested above ground Gliricidia residues were applied to 3 compartmentalized equal sections of 2m radius around each isolated tree to form three treatments. They are; T1: ^{15}N labelled above-ground Gliricidia residue added + ^{15}N labelled Gliricidia roots intact in the respective soil compartment; T2: the similar amount of non-labelled above ground Gliricidia residues added (as in T1) + ^{15}N labelled Gliricidia roots intact, and T3: non-labelled Gliricidia residues added + ^{15}N labelled Gliricidia roots removed. Four weeks after incorporation of Gliricidia residues to respective plots, a maize crop was planted. Nitrogen cycling and corn growth and yield were recorded. ^{15}N distribution among different plant parts of Gliricidia after four weeks of injection indicated a greater recovery of injected ^{15}N. Approximately 71%, 15% and 1.72% were recovered from the stems, leaves and roots. From the amount of % ^{15}N injected (294.49mg per tree) % ^{15}N overall recovery was around 87% by the Gliricidia trees. ^{15}N recoveries by the subsequent maize crop were around 13%. Of this quantum, approximately 10% of N was recovered from leaves and stems of Gliricidia residues, while around 2% was recovered from root residue of Gliricidia. Soil organic C and N contents increased with the addition of Gliricidia residues up to 4-6 weeks and gradually declined with time. The soil C and N contents were lower in deeper soil layers. Soil C derived from Gliricidia residues ranged between 21-36%. The injection of tracer N provide relatively easy ways to determine the transfer of ^{15}N into trees and it promises to be an effective way to evaluate N transformation and cycling in mixed cropping systems.

Impacts of anthropogenic nitrogen inputs on the spatial variation in greenhouse gas exchange at global scale

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Anthropogenic perturbation of the global nitrogen (N) cycle affects the Earth's climate due to manifold impacts on the N and carbon (C) cycles and thus on emissions of the greenhouse gases nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4). Warming effects include (i) N-induced increases in emissions of N_2O and CH_4 from soils, sediments and water bodies and (ii) NOx emission-induced tropospheric O3 formation, leading both to direct warming and to reduced C sequestration in forest biomass and soils. Cooling effects include (i) N-induced increases in net ecosystem production (NEP) and related C sequestration in tree biomass, soils, inland waters and oceans and (ii) N-induced aerosol formation. Here we quantified the N-induced warming and cooling effects and in the resulting net effect at the global scale and its spatial variation, the latter being unique. Impacts of anthropogenic N inputs on N2O, CO2 and CH4 exchange were quantified for the base year 2010 and for 2050 in response to six scenarios. This was done with an empirical approach and a process-based model (DLEM), accounting for the spatial variation of impacts. The six scenarios included a selected combination of (i) Shared Socio-economic Pathways, with narratives leading to expected changes in population, income, consumption and trade, combined with related Representative Concentration Pathways focusing on climate change and nitrogen mitigation effects at three different ambitions. Results of the empirical and model-based approach suggest that the global scale cooling impact of N-induced C sequestration (ca 2.2-2.7 Pg CO_2 eq. yr^{-1}) is slightly larger than the warming impact of enhanced N_2O and CH_4 emissions (ca 1.8-2.0 Pg CO_2 eq. yr^{-1}), but results vary strongly in space. Hotspots for anthropogenic N-induced N_2O emissions are predicted for China, India, Western Europe, East Africa and Central US, where agricultural activities are intense. Significant impacts of N input on CO_2 exchange occur in southern China, India, South Asia and part of Africa. When also accounting for the reduced C sequestration in forest biomass and soils in response to NO_x emission-induced O_3 formation (near 0.7 Pg CO_2 eq. yr^{-1}) there is a likely a very slight global warming effect. One should realize that accounting for the N emission-induced CO_2 equivalent emissions due to short lived climate forces, including ozone forcing, methane lifetime reduction and particulate matter formation, there is a cooling effect

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Nitrogen oligotrophication: How can it be?

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Abstract
While much research over recent decades has focused on the negative effects of excess nitrogen (N), evidence is mounting that large areas of the planet are suffering from N shortages. These shortages are caused by a process of N oligotrophication where increases in growing season length and temperature, increases in atmospheric carbon dioxide (CO_2) levels, and deacidification increase plant and microbial demand for N relative to supply. This process creates positive feedbacks by decreasing the C:N ratio of plant detritus that further reduces N availability. This presentation will review evidence for N oligotrophication at the Hubbard Brook northern hardwood forest long-term ecological research site in New Hampshire, USA. At this site, watershed-scale exports, internal cycling rates, and gaseous losses of N have declined in recent decades, often independently of levels of atmospheric deposition of N. These declines in N cycling have been accompanied by increases in microbial biomass C and respiration supporting the idea that oligotrophication is driven by interactions between climate and N and C cycles. These changes have implications for ecosystem productivity, C uptake and sequestration, food chain support, and response to disturbance events.

Spatially explicit targets for nitrogen use efficiency to keep food production within environmental boundaries

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Sustainable nitrogen management entails maximizing nitrogen's benefits for crop production while minimizing detrimental environmental impacts. Increasing nitrogen use efficiency (NUE, defined as the fraction of total N input taken up by crops) is a key leverage point for achieving this dual objective. However, the degree to which agricultural N pollution currently exceeds environmental boundaries varies strongly across regions (see Schulte-Uebbing et al., accepted). This regional variation should be accounted for when defining targets for NUE that reconcile crop production and environmental protection.

This study uses a global-scale, spatially explicit N balance model to derive regional targets for improvements in crop system NUE, and assesses to what extent best management practices can increase NUE to reconcile food production with N boundaries. We quantify regional target NUEs to maintain crop production while respecting thresholds for N runoff to surface water in view of eutrophication impacts, N leaching to groundwater in view of drinking water quality, and NH_3 emissions and related N deposition on terrestrial ecosystems in view of biodiversity loss. The derived NUE targets are then compared to spatially explicit 'maximum feasible' NUEs, which are estimated using data from crop fertilization that measure N input (from fertilizer, manure, BNF, atmospheric deposition) and crop N uptake for different crops, management and site factors. This data us used to determine factors that explain variation in cropping system NUE, and to build a regression model that predicts NUE as a function of these factors. Finally, we estimate the potential for global and regional crop production within N boundaries (crop production levels that can be obtained while respecting boundaries for all three N-related thresholds, expressed as a share of current production) at both current NUEs and at 'maximum' NUEs that can be obtained by adopting best N management practices. Results will be presented at the Workshop.

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N human inputs into the biosphere: nutrient imbalances and their impacts on environment, food security and human wellness

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The human inputs of nitrogen into the biosphere are increasing and now reach values around 300 Tg year due to the global anthropogenic nitrogen emissions from fossil fuel combustion processes, fertilizer production and biological N fixation in agriculture. We will discuss these N inputs and their consequences including those of the nutrient imbalances that they generate. Among them, the global N/P ratio of anthropogenic inputs has increased from 19 ± 1 in the 1980s to 30 ± 2 in 2020 with multiple impacts for nature and humans.

The ratios of N:P inputs tend to be higher in areas with low livestock densities that are treated with inorganic fertilizer. Instead, in areas with high densities of livestock, particularly monogastric (nonruminant) livestock, such as poultry and pigs, leachates tend to be rich in P, with low N:P ratios and large amounts of P are released through estuaries to oceans, as observed in some Indian rivers.

N:P increases in media (soil or water) directly affect organismic N:P ratios and growth, which subsequently drive shifts in the community diversity and in the trophic web structure and function. But high levels of N fertilization and of N:P ratios, also can potentially affect to humans.

N fertilization has historically been excessive in rich countries leading to over-production of food, whereas the low use of fertilizers has staved off malnutrition in poor countries. Men born in rich countries in the 1980s were an average of 1.5 cm taller than men born in the 1960s, whereas the height of males born in the same decades in poor countries did not differ. Differences in per capita N, P, and N:P intake explained these differences in the height of men born in rich countries better than did socioeconomic and sanitary variables, such as gross domestic product, the human development index and birth weight according with FAO, OCDE and WHO integrated data analyses. The intensification of crop management and use of fertilizers (especially N) have changed the composition of food intake per capita. The global intensification of N fertilization increases the allergenic proteins concentrations in wheat thus increasing the mean annual per capita intake of these proteins and therefore the risk of higher prevalence of some illnesses such as coeliac pathology.

Finally, we will discuss the projections resulting from the expected further rising of N inputs and its impacts on human health together with those of the generated nutritional imbalances in nature.

Region oriented and integrated approach to reduce emissions of nitrogen and greenhouse gasses to the environment

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Agricultural practices are causing a variety of environmental impacts such as airborne emissions of ammonia and greenhouse gases and leaching and runoff of nutrients to groundwater and surface water. Measures have to be taken to achieve environmental goals set in international agreements and directives, such as the Habitats Directive (biodiversity), Nitrates Directive (nitrate leaching to groundwater), Water Framework Directive (nitrogen and phosphorus runoff to surface water) and the Paris Agreement (goals for greenhouse gas emissions). For finding a solution for these issues an integrative approach is needed in order to include synergies between measures and to avoid pollution swapping. In addition, the spatial interaction is required because emissions are related to the spatial distribution of nature, farming systems, soil type and hydrology. In a previous study with Netherlands as example, an integrated approach was applied to support policy making related to environmental issues on nitrogen, water and climate at a national scale (Gonzalez-Martinez et al., 2021). We now performed an approach with tailormade measures taking regional aspects into account. In this presentation we will show results of such a regionalized approach for the Netherlands using a suite of models, including the INITIATOR model for the manure and fertilizer distribution and the emissions of ammonia and greenhouse gases, the Animo model for the N leaching to groundwater and N and P losses to surface waters, and the Roth-C model for carbon sequestration. Results are presented for the most optimal mix of structural, technical and management measures in the different regions to achieve the targets on both regional and national level. The region specific approach is compared with a more generic (national) approach to explore the most effective solutions, for the current environmental problems.

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Urban Nitrogen Budgets – Comparison Across Cities

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Reactive Nitrogen (Nr) flows are mostly analyzed in an agricultural context (e.g. agricultural land N budgets, farm N budgets etc.). However, a large share of Nr consumption and emission takes place in the urban environment as it is home to over 50% of the world's population. This makes cities not only a place of consumption and potential pollution but also a place of opportunity for Nr recycling and effective policy implementation for mitigation (Winiwarter et al., 2020). Since little information is available on N flows through the urban environment, these opportunities often remain unexploited.

To enhance knowledge in this field we developed a framework to model the path of Nr through a city and its surrounding area and applied it to four test areas (Beijing, Shijiazhuang (China), Vienna (Austria), and Zielona Góra (Poland)). Comparing the results, taking advantage of harmonized indicators (e.g. flows per capita/area, self-sufficiency, recycling rate), allows to validate assumptions drawn from a single city and enables a learning process from each other.

Our findings demonstrate marked differences in all cases between the core and the surrounding area with the core area being a place of Nr consumption with biggest flows between industry (goods including food), household, waste, and wastewater, whereas the surrounding area was identified as a place of agricultural production with highest flows between industry (fertilizers) and urban plants. As a result, highest emissions to the atmosphere in the core area stem from combustion processes, with flows to waste and wastewater opening up potential further release pathways to the environment. Emissions from livestock and agricultural land play a bigger role in the surrounding area, indicating a need for mitigation measures beyond combustion. Nr recycling is rather low in the European cities (0% - 6%) whereas in Shijiazhuang more than 30% of N inflow is recycled from sewage sludge and food waste to agricultural land and to livestock as fertilizer and feed.

These findings identify common patterns as well as differences, deepening our understanding of Nr flows through the urban area as well as showing us what could potentially be done to increase Nr recycling by looking at differences.

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Recovery of ammonia from livestock and municipal wastewater using gas-permeable membranes: Effect of carbonate alkalinity

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Abstract

Conservation and recovery of nitrogen (N) from animal wastes and industrial effluents is important because of economic and environmental reasons. The gas-permeable membrane process includes the passage of gaseous ammonia (NH_3) through a microporous, hydrophobic membrane, and capture and concentration in a stripping solution on the other side of the membrane. The membrane manifolds are submerged in the liquid and the NH_3 is removed from the liquid before it escapes into the air; the NH_3 permeates through the membrane pores reaching the acidic solution located on the other side of the membrane. Once in the acidic solution, NH_3 combines with free protons to form non-volatile ammonium (NH_4^+) ions that are converted into a valuable NH_4^+ salt fertilizer, which is desirable to export N off the farm to other regions where N is needed. This research determined the role of inorganic carbon (bicarbonate alkalinity) on the effectiveness of ammonia recovery using gas-permeable membrane technology and low-rate aeration. There were two distinct and interconnected mechanisms in this new approach. One was the release of hydroxide from the natural carbonates that increased the wastewater pH and promoted gaseous ammonia formation and membrane uptake. The other was the release of acidity and consumption of alkalinity by the nitrogen recovery process with the gas-permeable membrane. This acidification of the wastewater can completely halt the N recovery process. Therefore, an abundant inorganic carbon supply in balance with the ammonia in wastewater is needed for a successful operation of the technology and efficient recovery of the ammonia. Fortunately, most swine manures contain ample supply of endogenous inorganic carbon and the process can be used to more economically recover ammonia using the natural inorganic carbon instead of expensive alkali chemicals. The process can be combined with phosphorus precipitation and therefore produce two recovered nutrient steams: ammonia and phosphate concentrates.

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Futurability of our nitrogen use connecting humanity and nature

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Nitrogen (N) provides great benefits to humanity as fertilizers for food production and materials for industrial production. However, production and consumption of food, goods, and energy creates huge loss of reactive N (N compounds other than inert and harmless dinitrogen) to the environment that threatens human and ecosystem health via N pollution with various impacts from local to global scales. We need to address this tradeoff––N issue––to achieve our sustainable N use. The present knowledge of the N issue leaves much to be elucidated, e.g., ecosystem responses to human-induced N inputs and removals, N flows within human society and to the environment for each reactive N species, and physical and economic effects of policy, technology, and behavior changes on the N issue. A new N use is attracting attentions in Japan, i.e., ammonia as an energy source. Ammonia does not create carbon dioxide when combusted, and therefore the momentum of decarbonization focuses on this property. It is, however, concerned that the fuel ammonia may change the global N supply chain and increase emissions of nitrogen oxides. Our new 6-year project––Sustai-N-able––(RIHN, 2022) tackles the N issue covering all the human N uses for fertilizers, materials, and fuels considering their linkages in-between natural and human systems. Study achievements will produce a tool to assess the benefits and threats of N use that supports policy decision making to address the N issue. We will narrate interdisciplinary and transdisciplinary knowledge on the N issue engaging domestic and international stakeholders and also practice the Future Design (Saijo et al., 2022) with them towards the sustainable N use. Our goal, hopefully in 2050, is to achieve the "futurability" of our N use resolving the N issue and to let future generations inherit the food equity and good health of humanity and nature.

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Fertilization strategies in organic winter wheat for bread quality

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The objectives of this study are to evaluate different application strategies of organic fertilizers to obtain high yield and bread quality in organic winter wheat production.

To study the effects of and interactions between fertilizer type, timing, soil incorporation and irrigation, two large 4-factorial experiments were conducted in 2020 and 2021. In order to separate the effects of different topdressings from the first fertilizer application, all plots received the same amount of N with mineral fertilizer in early spring and then received different organic fertilizers as top dressing at various times. The organic fertilizers were biogas digestate (BD), poultry manure (PM), mixture of BD and PM (BD/PM), meat bone meal pellets (MP) and vinasse (VI). The different times for top dressing compared were at start of crop growth in spring (GS21), at stem elongation (GS32) and late boot stage (GS45). In four other field experiments, on silty clay and sandy loam in 2021 and 2022, applying the entire nitrogen amount with the organic fertilizer at GS 21 was compared with splitting it into two halves. The second application occurred either at GS 32 (for MP in 2021 and MP and VI in 2022) or at GS 39-45 (for BD and VI in 2021 and BD in 2022).

In the dry year 2020, the irrigation increased yield by on average 650-700 kg/ha but reduced protein content (9,5% with soil incorporation and 9,2% without) compared to non-irrigated (12,0% with soil incorporation and 11,1% without). Nitrogen yield was also reduced by irrigation (74 kg Nha^{-1} with soil incorporation and 71 kg Nha^{-1} without) compared to non-irrigated (81 kg N/ha with soil incorporation and 74 without), at least in plots with BD or VI. Soil incorporation did not affect yield, but had a positive effect on both protein content and nitrogen yield, at least in treatments without irrigation. There was a tendency for reduced yield and increased protein content with later fertilization.

In 2021, protein, yield and N offtake were all larger after early (GS 21) than later (GS 32 and 45) fertilization. For BD this reduction was very small. Due to satisfactory amounts of precipitation in spring 2021, irrigation was only performed after the fertilization in GS 45. That did mainly have an effect in the treatment with late fertilization with PM. In the other experiments, one single early application rather than split gave a higher yield for all organic fertilizers, but nitrogen offtake was often similar. For BD and VI protein was in some cases higher after split application, but for BD and MP in 2022 split application did have the opposite effect.

In conclusion, most organic fertilizers is best utilized if all is applied early. Only fertilizers with a large fraction of very readily available N is suitable for application at stem elongation or later, and then mainly to be able to make a later decision on total fertilization rate.

Global nitrogen demand, waste, and potential circularity under nationally sourced *EAT-Lancet* diets

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The EAT-Lancet diet has been proposed as a healthy and environmentally sound diet with universal applicability, but the feasibility of sourcing it nationally has yet to be explored. This is especially important as current overdependence on trade is increasing the vulnerability of many nations to food-trade shocks and supply chain disruptions that can lead to local food shortages, as evidenced by COVID-19 and the recent war in Ukraine. These issues can be alleviated by exploring scenarios of healthy and sustainable food production at national scales, especially for low-income nations. Using FAOSTAT production data for 204 nations and the EAT-Lancet Commission guidelines, we calculated needed food-system interventions for a plausible diet within EAT-Lancet constraints that can be sourced from each nations' agricultural land. While 95% of the global population live in countries which would not be limited by land availability to source these diets, the changes to nitrogen agricultural use are substantial. Nevertheless, such scenarios also provide opportunities for exploring the implementation of short nutrient cycles and increased circularity.

Revealing stakeholders' perceptions of N-fertilizing practices in SUDOE herbaceous agroecosystems

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Agronomic practices are associated with a complex combination of positive and/or negative impacts of different nature (i.e., yields, soil properties, costs, etc.). As a result, stakeholders' views on different agronomic practices are heterogeneous or even opposed, and within a same stakeholder group individual opinions may differ. Such a diversity of opinions can reveal the existence of barriers to the reduction of N losses in agriculture but can also provide clues to the overcoming of such barriers or to the identification of opportunities for the adoption of best fertilizer-management practices towards N neutrality in agroecosystems. In this research we use Q methodology to map stakeholders' views about agricultural practices in three herbaceous farming regions of the SUDOE (Southern EU) territory: the Garona basin in France, the upper and middle Tagus basin in Spain, and the lower Tagus basin in Portugal. We conducted interviews to two types of stakeholders (farmers and experts), that were asked about the priority that should be given to the implementation of 34 agronomic practices, including N fertilization methods. With this research we aim to identify the main differences and similarities on how stakeholders perceive agronomic practices and their relation to optimal land management regarding nitrogen use efficiency and enhanced sustainability of agroecosystems.

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Recoupling global livestock and crops through managing trade

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Reactive nitrogen (Nr) losses from global crop and livestock production are threatening environmental and human health. Decoupled crop and livestock production systems in the context of globalized trade, featured by overuse of synthetic N fertilizers and non-recycled manure, are the major contributors resulting in such a threat on a global scale. By synthesizing data of 78 crop types and 11 animal types in 144 countries from 1961 to 2010, we found that decoupling of crop and livestock production is speeding up with substantial variations in crop-importing and exporting countries. In 2010, manure loading was over-capacity on 44% of global croplands and insufficient on 25% of global croplands. However, if no international trade, decoupling of crop and livestock would not be solved given the different N requirement of crops and livestock in different countries, while optimizing international trade based on coupling crop and livestock production would reduce 30% of manure N losses and transportation cost. Our research suggests that enhancing management of virtual N embedded in trade is essential for achieving a coupled crop-livestock production systems.

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A one-way journey from land to sea: the N cycle in rivers, lakes, estuaries and coastal ecosystems

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Nitrogen Terrestrial inputs of reactive nitrogen (hereafter Nr) have increased tenfold over the last century, from 15 Tg N in 1860 to 187 Tg N per year in 2005 (Galloway et al., 2008). While this has enabled an unprecedented increase in global food production, the alterations to the global nitrogen cycle are also unprecedented, with planetary-scale consequences that also affect all known ecosystems. Some of the reactive nitrogen introduced through agricultural systems leaches from the soil into inland waters, both surface and groundwater. Increased Nr in freshwaters can cause serious disturbances to aquatic organisms and has detrimental consequences for water quality. However, the journey of Nr from terrestrial to aquatic systems does not end there: via rivers and groundwater, Nr reaches estuaries and coastal waters, thus affecting marine ecosystems.

From sources to sinks, I will review the role of N as a connecting element between land and sea, analysing transfers, processing and cascading effects along the aquatic continuum. I will discuss how climatic and hydrological gradients affect these transfers and to what extent socio-economic development and changes in global water resources may affect land-sea N fluxes and the functioning of aquatic ecosystems in the coming years.

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Barriers and opportunities for developing next-generation enhanced efficiency fertilizers

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To feed the world's growing population without further threatening the environment and ecosystems, the efficiency of nitrogen (N) fertilizers needs to increase significantly. The enhanced efficiency fertilizer (EEF) technology has shown promise in decreasing N losses to the environment. EEFs regulate the release of N in dependence of external stimuli (controlled release fertilizers) and inhibiting the activities of enzymes involved in processes conducive to N losses (urease and nitrification inhibitors). This presentation will discuss the limitations of these EEFs and the need of making a breakthrough in EEF development. This would require concerted research efforts from multi-disciplinary expertise that integrates agronomy and soil science with synthetic chemistry, chemical engineering, plant physiology and plant biochemistry. We argue that the recognition and monetization of the avoided social costs of using EEFs are necessary for incentivizing the adoption of innovative N fertilizers. This will avoid enormous spending on cleaning up N pollution while ensuring global food security. The newly established A$17m over five years Smart Fertilisers Research Hub (funded by the Australian Government, industry partners, Incitec Pivot Fertilisers and Elders, and universities) aims to transform agriculture by delivering new N fertilisers and decision-making tools that increase efficiency of use by crops and reduce losses to the environment.

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Leached nitrogen losses from urea fertiliser with and without urease and nitrification inhibitors

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Urea is the most widely used nitrogen (N) fertiliser globally, but it is associated with significant reactive N (N_R) losses into the environment, predominantly via ammonia volatilisation. To address this problem, urea can be coated with urease inhibitors, such as N-(n-butyl) thiophosphoric triamide (NBPT), which have been shown to effectively reduce ammonia emissions from surface-applied urea. However, studies assessing the efficacy of urease inhibitors predominantly focus on gaseous N_R losses. We hypothesise that the use of urease inhibitors with urea may lead to greater leaching losses of N_R as urea-N. To test this hypothesis, we packed columns (0.13 x 0.20 m; diameter x depth) with a Dystric Cambisol, planted with Spring wheat (Sokoll-N, two plants in each column), and performed 7 leaching events, each equivalent to a 25 mm precipitation-event, over a 10-week period following N application. Four N treatments were assessed: a zero N control (C), urea (U), urea coated with NBPT (UUI), and urea coated with NBPT and the nitrification inhibitor dicyandiamide (DCD; UDI). Nitrogen was applied at a total rate of 210 kg N ha^{-1}, split as 40 and 170 kg N ha^{-1} at the basal and three-leaf growth stages, respectively. Phosphorus and potassium were supplied at recommended rates for Spring wheat. Leachate was collected from each column over a 4 h period following each precipitation event, and concentrations of urea-N, ammonium-N, total oxidized N (TON; comprised of NO_3-N + NO_2-N), and total N in the leachate were measured. Leachate urea-N concentrations peaked for the U treatment in the second leaching event at 2.5 mg N L^{-1}, whereas under the UUI and UDI treatments peak concentrations of 19.9 and 20.7 mg N L^{-1} occurred on the second and first leaching event, respectively. The dominant N loss via leaching was as TON, with concentration peaks of 135, 238, 268, and 198 mg N L^{-1} for C, U, UUI and UDI, respectively. Overall, urea-N accounted for 1.5, 1.1, 5.5 and 5.7 % of total N leached for C, U, UUI, and UDI, respectively, TON accounted for 77.9, 93.7, 85.4 and 88.6 %, respectively. We conclude that TON is the dominant N form leached from all the urea-based fertilisers examined, making the use of nitrification inhibitors with urea an appropriate means of reducing TON losses. However, urea-N leaching is significant when urea is treated with urease inhibitors and studies assessing urease inhibitors should aim to include urea or total N analyses to account for all N leaching losses.

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Nitrate leaching in maize and wheat irrigated cropping systems under nitrification inhibitor and/or intercropping effects

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The use of nitrogen fertilizers in agriculture is currently under high pressure to reduce its environmental impact and improve its currently low efficiency. Nitrification inhibitors and/or intercrops had emerged in recent decades as useful tools to combat these problems. The objective of the experiment is to study the effect of these techniques on the yield, the nitrogen use efficiency (NUE) and N leaching in a maize-wheat rotation. Six treatments were studied, combining the use of ammonium nitrate sulfate (ASN) alone or with a nitrification inhibitor (DMPSA or 3,4-dimethylpyrazole succinic acid) and the use or absence of vetch (*Vicia sativa* L.) as intercrop (Allende et al., 2022). The results showed that fertilized treatments did not show significant differences in crop development, but the use of DMPSA delayed the nitrate (NO_3^-) availability and reduced N leaching losses (average N leaching reductions around 25% after maize harvest). On the other hand, the use of vetch as intercrop helped to reduce the negative effects of N deficiency and, at the same time, increased the concentration of N in the soil during the following crops (4.5 kg N ha^{-1} on average after wheat harvest) and reducing its losses due to leaching (average N leaching reductions around 14% after maize-wheat season). The combination of both techniques (DMPSA and vetch intercrop) at the same time presented a synergic effect and improved greatly the environmental impact of the irrigated maize-wheat system.

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Reducing reactive nitrogen losses and improving nitrogen use efficiency in rice-wheat system using nitrification and urease inhibitors

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Neem oil a nitrification inhibitor and limus a urease inhibitor have been reported to improve the nitrogen use efficiency (NUE) in crops. A field experiment was carried out to quantify loss of reactive nitrogen (N) fluxes and global warming potential (GWP) of wheat and rice crops with neem oil coated urea (NCU), limus coated over NCU (LCU), prilled urea (PU) and no nitrogen control. The measurement of nitrous oxide (N_2O), methane (CH_4) and ammonia (NH_3) emissions, mineral N leaching and plant N uptake was carried out under the different treatments in wheat and rice crops during 2018 rabi and 2019 kharif seasons. The GWP of rice-wheat system was reduced by 11.9 and 15.1% with the application of NCU and LCU, respectively, as compared to PU. The total loss of applied N through NH_3 volatilization, N_2O emission, and mineral N leaching pathway was significantly different between PU and LCU treatments; however, the difference was not significant between PU and NCU. Among the treatments, the total loss of N through the different pathways ranged from 26.1% with LCU to 29.8% with PU in rice and from 18.9% with LCU to 24.7% with PU in wheat. The N uptake was higher by 12.8 and 4.7% in rice and by 13.0 and 6.4% in wheat with LCU and NCU, respectively, as compared to PU. The total NUE ranged from 42 to 56% in rice and 45 to 62% in wheat under the different treatments. Thus, the use of urease and nitrification inhibitors together coated with urea may help in reducing reactive N losses and improving the NUE of rice-wheat system which occupies around 10.5 Mha of area in the Indo Gangetic Plains.

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Effect of tillage and DMPSA on the fate of N and N_2O emission in a Mediterranean barley crop. A field ^{15}N tracing study.

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A ^{15}N tracing field experiment was performed in order to study how soil management and the use of the nitrification inhibitor DMPSA could affect N fate of, including soil retention, plant recovery and N_2O emissions. The experiment was set up in Madrid, with barley (*Hordeum vulgare* L. var. 'Esterel R1') under rainfed conditions. The experiment consisted in a split-plot design with tillage as main factor (no tillage, NT, and tillage, T) and fertilizer as second factor (unfertilized control, N0, ammonium nitrate, AN, and AN with the nitrification inhibitor, AN+DMPSA). The AN was enriched with ^{15}N, being labeled in the NH_4^+ (^{15}AN) or in the NO_3^- (A^{15}N). Two liters of fertilizer solutions (80 kg N ha^{-1}) were applied at top dressing fertilization in 1 m^2 microplots. The ^{15}N analyses in soil mineral N revealed that 75.4 % and 41.6 % (on average) of NH_4^+ and NO_3^- were derived from N fertilization, respectively. Furthermore, AN+DMPSA enhanced the NH_4^+ concentration derived from ^{15}AN. Differences regarding soil management were only observed in the endogenous NO_3^-, being higher in T than in NT plots. From top dressing fertilization and until harvest, cumulative N_2O fluxes decreased in the order AN > AN+DMPSA > N0, being the emissions from AN+DMPSA decreased by 60.3 % in comparison to AN-only. The use of DMPSA was effective in reducing the N_2O derived from both soil endogenous N and AN fertilizer. Only the 15.3 % of N_2O emission until harvest were derived from fertilizer, being higher the proportion derived from ^{15}AN than that from A^{15}N. Thus, nitrification may be the predominant process involved in the N_2O emission after top dressing fertilization. On average, 22.4 % of the N applied at dressing was recovered in barley plants. The non-tilled plots increased N recovery in aboveground biomass and tended to increase the total N recovery with respect to the tilled plots. Mean plant N derived from A^{15}N was higher than that derived from ^{15}AN. Residual N in soil derived from fertilizer was analyzed five months after harvest at three depths (0-10, 10-20 and 20-40 cm). The total soil N residual (0-40 cm) ranged from 28.6 % in NT-AN to 49.5 % in T-AN+DMPSA. Soil residual N in the upper layer was 57 % higher in AN+DMPSA compared to AN-only. Tillage increased residual N in soil compared to NT. In summary, our results showed that the DMPSA inhibitor was effective in the mitigation of N_2O emissions derived from fertilizer and from endogenous N, which was the main contributor to N_2O emissions in this rainfed semi-arid agro-ecosystem. Tilled and non-tilled plots increased the recovery in soil and crop, respectively.

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Degradation of the Nitrification Inhibitor 3,4-Dimethylpyrazole Phosphate in Soils: Indication of Chemical Pathways

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Intensive application of nitrogen-based fertilisers has become a common practice to achieve high yields. However, a large proportion of the applied nitrogen is lost to the surroundings causing unwanted consequences. Fertilisers amended with nitrification inhibitors (NIs) are used as a strategy to minimise N-losses and improve overall N-use efficiency. 3,4-Dimethylpyrazole phosphate (DMPP) is the most successful NI to date but has a highly variable efficacy. The degradation products of DMPP have not been identified and there is a lack of understanding about whether the insufficient stability of DMPP contributes to the inconsistent performance. This work used a systematic approach to identify the degradation products of DMPP and 3,4-Dimethylpyrazole glycolate (DMPG) for the first time. Experiments were performed using sterilised and non-sterilised soils, as well as using an accelerated weathering machine in the absence of soil, to differentiate between the chemical and microbial degradation pathways. The similar outcome obtained for the degradation under these varied conditions suggests chemical and not microbial degradation of the inhibitor. The degradation process could potentially be initiated by reactive oxygen species (ROS) formed through both biotic and abiotic processes in soils. These findings will help develop guidelines for synthesis of new NI compounds with reliable performance.

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The quest for efficient nutrient restoration strategies of aquatic ecosystems: an exploratory study

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The EU Green Deal and the Zero Pollution Strategy call for a drastic reduction of nutrients in the environment and the design of efficient strategies to reduce pollution. Nutrient reduction targets can provide quantifiable values on the way to achieving overarching environmental quality objectives for freshwater and marine ecosystems. Targets can be attained in different ways, but efficient strategies are those that achieve the best target at minimum cost. Identification of efficient strategies is not trivial, because it must consider physical and policy constraints, as well as trade-offs and non-linear cost-benefit relationships.

In this work we explore potential efficient strategies to achieve the environmental target of reducing nitrogen loads to the sea in the Vistula River Basin, taken as an example for the Baltic region. The environmental target of nitrogen load reduction was identified considering the ecological condition and needs of the basin coastal areas. We applied a tool that integrates an optimisation routine with the Geospatial Regression Equation for European Nutrient losses model [GREEN; Grizzetti et al., 2012], as implemented in the open source R-routine of Udias et al. (2022). The GREEN model assesses total nitrogen (and total phosphorus) load from a basin given diffuse (mineral and manure fertilisers, nitrogen crop and soil fixation) and point (urban and industrial wastewater discharges) emissions to the land and river network. We first consider nitrogen load to the sea in current conditions (2014-2018) and distance to the environmental target. Further, we seek efficient strategies (Pareto Optimal) that may achieve it, by reducing nitrogen emissions to the basin from different sources. Finally, we compare some example strategies considering their potential costs and environmental outcomes, such as estimated changes in freshwater concentrations along the stream network. While hypothetical, the exercise shows the size of investment in natural resources management that should be required for achieving good ecosystem conditions in fresh and coastal waters to fulfil the ambitious European objectives, and the usefulness of exploring alternative strategies.

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Integrated policy options to reduce future nitrogen load to surface waters

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Human activities have altered the nitrogen (N) cycle since the start of the previous century. The growing population and the growing food demand has led to increased emissions from fossil fuel combustion, N fertilizer production and use and animal manure. This has resulted in increasing nutrient loading of freshwaters through losses from agricultural land by leaching and runoff, discharge of wastewater in urbanized areas, and atmospheric N deposition and thus an increasing nitrogen concentration in many water bodies across the world.

Using an integrated assessment model we show the future effect of different integrated policy options in an SSP2 ('middle of the road') world on river loading and export of nitrogen. Four options are considered: (i) change towards more mixed landscapes of agriculture and nature; (ii) improved nitrogen use efficiency in crop production; (iii) reduction of nutrient losses by runoff through a restoration of riparian buffer zones along rivers and lakes flowing through agricultural areas; (iv) reduction of emissions by human and industrial (point) sources to surface water. Projected changes of river nitrogen loading and export for the recent past (1970-2015), and scenarios with different combinations of the policy options for the future period up to 2070indicate that an optimal combination of the four options is needed to prevent a further increase of nitrogen loading and export to coastal waters.

Long-term trajectories of nitrogen and phosphorus point sources from wastewater to German river systems

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Concurrent excesses of nitrogen (N) and phosphorus (P) compounds in the environment are causing the eutrophication of water bodies worldwide, including the North Sea and the Baltic Sea that border Germany. Specifically, not only the N concentration in water but also the N:P ratio, which characterizes the nature of nutrient limitation, are crucial measures of the state of aquatic ecosystems. While many studies focus on the diffuse sources of N and P, point sources from urban and industrial wastewater can substantially contribute to in-stream N and P levels. Yet, systematic studies of the co-development of N and P point sources that span different river basins and a long time period are greatly lacking at a national scale like Germany.

In this study, we aim to investigate the long-term trajectories of N and P point sources in German catchments over the last seven decades (1950-2019). We construct a novel gridded dataset of N and P point sources for Germany, adapting the methodology proposed by Morée et al. (2013) and using a large range of country-specific information on population counts, protein supply, food wastes, detergent P consumption, population connection to sewer and urban wastewater treatment plants, and industrial wastewater release. Our reconstruction approach accounts for the uncertainty in coefficients (e.g. efficiency of wastewater treatment, wastewater losses in sewer). We create an ensemble of plausible point sources realizations resulting from different combinations of coefficient values that are constrained by the recently observed N and P loading from urban wastewater treatment plants.

From the newly constructed dataset, we discuss the trajectories of N and P loading and the N:P ratio across major German river basins. N and P loadings show large differences between West and East Germany. In the 1980s and early 1990s, P loading exhibits a stronger decrease than N loading because of the introduction of phosphate-free laundry detergents. Overall, N and P trajectories have large temporal and spatial variations, in particular due to differences in treatment efficiency, in population density, and in regulations that limit the maximum phosphate content in detergents. Our study highlights the importance of considering both N and P point sources, as well as their spatial and temporal developments, in water quality assessments.

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Strong hydroclimatic controls on vulnerability to subsurface nitrate contamination across Europe

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Subsurface contamination due to excessive nutrient surpluses is a persistent and widespread problem in agricultural areas across Europe. The vulnerability of a particular location to pollution from reactive solutes, such as nitrate, is determined by the interplay between hydrologic transport and biogeochemical transformations. Current studies on the controls of subsurface vulnerability do not consider the transient behavior of transport dynamics in the root zone. Here, using state-of-the-art hydrologic simulations driven by observed hydroclimatic forcing, we demonstrate the strong spatiotemporal heterogeneity of hydrologic transport dynamics and reveal that these dynamics are primarily controlled by the hydroclimatic gradient of the aridity index across Europe. Contrasting the space-time dynamics of transport times with reactive timescales of denitrification in soil indicate that approximately 75% of the cultivated areas across Europe are potentially vulnerable to nitrate leaching for at least one-third of the year. We find that neglecting the transient nature of transport and reaction timescale results in a great underestimation of the extent of vulnerable regions by almost 50%. Therefore, future vulnerability and risk assessment studies must account for the transient behavior of transport and biogeochemical transformation processes.

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Optimizing Denitrifying Bioreactor Installation in the Chesapeake Bay Watershed to Treat Legacy N Pollution

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The Chesapeake Bay has been the recipient of decades of conservation efforts to reduce nutrient pollution, with varying success. In 2010, total maximum daily loads (TMDLs) were established for the Chesapeake Bay Watershed (CBW) to reduce nitrogen pollution by 24% before 2025. Though there has been improvement in the water quality of the Bay since the inception of the TMDLs, the reductions made to date will not be enough to achieve the goal by the deadline.

An emerging best management practice (BMP) with high potential to achieve cost-effective nitrogen abatement is the installation of denitrifying bioreactors to remove legacy nitrate that is stored for decades in aquifers and released via groundwater springs. Though previous research explores the application and cost-efficiency of denitrifying bioreactors compared to other BMPs, we are not aware of an analysis to date that investigates how to strategically prioritize the placement of bioreactors throughout the watershed.

We develop a bioeconomic model to determine the cost-minimizing spatial placement of bioreactors to achieve nitrogen abatement reductions while considering biophysical constraints in addition to factors that drive spatial heterogeneity in the per-unit costs of nitrogen removal. To do so, we develop a novel dataset that combines measured and spatially interpolated data at the national and spatial scale on location, median discharge, and nitrate contamination. The output of the model is the cost-minimizing spatial pattern of denitrifying bioreactors and the quantity of spring flow treated (i.e., diverted through the bioreactor) at a census of candidate spring sites throughout the watershed.

The findings of our analysis underscore the importance of combining economic and biophysical criteria to prioritize spring sites for bioreactor installation. In particular, the model prioritizes bioreactor placement at springs with high nitrogen loads and delivery factors close to 1. We demonstrate the optimal pattern of bioreactor placement under increasingly stringent nitrogen abatement targets to identify the marginal cost, or supply function, for nitrogen removals in the watershed. Our findings, displayed visually, identify hotspots for bioreactor placement efforts, which supports policymakers in targeting efforts and spending in those areas of the watershed that yield the greatest improvement in water quality at least cost. The findings of this study offer tangible solutions to measure nitrogen abatement, which may have ramifications in the nutrient market.

Three decades of nitrogen fluxes in freshwaters and to the seas in Europe: a historic and regional analysis

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Nitrogen (N) loads and concentrations in European fresh and discharged to marine waters from 1990 to 2018 were quantified with the conceptual model GREEN, to provide a historic perspective of nutrient pollution and management from inception of the European Urban Waste Water Treatment and Nitrates Directives in the 90ies to almost 20 years after the adoption of the Water Framework Directive. To account for regional differences, the model was calibrated independently for marine regions. Results are presented here for the four European Seas. Total N inputs were estimated at about 31.6 Tg/y in the early 1990s and 29.9 Tg/y in 2014-2018. Regional differences were large: from 1990 to 2018 N inputs decreased by 10% in the Atlantic Ocean, whereas they increased by 8% in the Black Sea region. Throughout the study period, atmospheric N deposition on land decreased by 17% and point source emissions by 22%. Conversely, an important breakpoint in N input trends was detected for agricultural diffuse sources: agricultural N inputs, particularly mineral fertilizers, decreased significantly during the first two decades but around 2008-2010 N inputs from agriculture began to increase again to levels close to the early 1990s.

Annual loads to sea were about 16% of inputs, and went from 5 Tg N/y in 1990-1994, down to 4.7 Tg N/y in 2014-2018, again with regional differences: N loads to the Atlantic Ocean decreased by 10% whereas loads to the Mediterranean Sea were reduced by only 3%. Lowering of N inputs helped reducing nutrient pollution in the freshwater stream network. The share of stream network length with mean annual TN concentration <2 mg N/L raised by 8%, whereas that of high concentration (>5 mg N/L) lowered by 7%. Improvements occurred in all regions, especially in land draining to the Atlantic Ocean and to the Mediterranean Sea. Despite improvements, current N concentrations in freshwaters remain above thresholds congruent with good ecological status in 45% of stream network. The approach pursued in this study highlights regional opportunities that can be exploited for further environmental gains, however sustainable nutrient management in agricultural land needs to play a key role for N pollution control across all Europe.

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Distribution of livestock populations and excretion relative to human populations in Canada: Implications for nitrogen circularity

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Canada's livestock sector is important economically and for food security. Understanding the spatial and temporal distribution of animals and excreted nutrients in relation to human populations is the foundation of strategies to sustainably manage the manure resources, a concept sometimes referred to as manure-sheds. Data from national censuses and targeted farm surveys, allocated to homogeneous soil polygons (SLCs), were used to quantify long term changes in standardized animal units and nutrient distributions by Canada's four key animal sectors and human settlements; we thus identify nitrogen concerns and strategies by sectors and regions. The export-driven beef and pig sectors are volatile, with the beef sector suffering a market setback following concerns over bovine somatic encephalopathy. Beef calf production has migrated westward to the open prairies with finishing feedlots concentrated in thinly populated areas of central and southern Alberta. Pig production has expanded from Quebec and Ontario to western Canada, esp. southern Manitoba where land and grain is abundant. In contrast, the dairy and poultry sectors which are tied more to domestic markets in Canada are relatively well dispersed across provinces in relation to increasing consumption, with dairy numbers somewhat declining due to improved production efficiency and poultry numbers growing. Dairy cows and chickens are more prominent near major markets and labour supplies in southern Quebec, Ontario and British Columbia. Manure nitrogen concentrations are generally low as most SLCs have fewer than one animal unit per agricultural hectare, and the numbers are lower per total SLC area (farmed and unfarmed). The greatest accumulation of nutrients from animal feed, fertilizer and human food occurs in the peri-urban areas of the three largest metropolitan areas: Toronto, Montreal-Quebec City, and Vancouver. As cities in Canada continue to grow in size, density and demand for food, so will the intensity of nitrogen accumulation. We have calculated the hypothetical dissipation of nitrogen across peri-urban SLCSs outward from city centroids. However, recycling wastes in Canada focuses on reuse of carbon for energy (combustion, anaerobic digestion) and soil amendment (compost), with currently limited effort to return the valuable nutrients, increasingly flowing into these areas, back to the farms where the crops are produced. Hence, the nitrogen consumed annually for food production is in effect lost through the farm to fork chain, with little recovered for reducing consumption of *de novo* nitrogen. We propose therefore an alternative paradigm for nitrogen circularity that might be called ‘farm to fork to farm’.

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Comparative consequential LCA: microbial fertilizers grown on potato wastewater, common organic fertilizers, and mineral fertilizers

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The production of chemical fertilizers (CFs) is linked to severe environmental impacts. Hence, the EU Farm-to-Fork strategy aims at reducing fertilizer use and increasing organic farming. However, certain commonly used organic fertilizers (OFs) have a higher environmental impact than CFs. Microbial fertilizers (MFs) produced on potato wastewater are a novel, currently underexploited resource with a high potential in Belgium. They provide a good alternative, since they allow the efficient recovery of nitrogen, phosphorus and potassium, while improving crop quality. Nevertheless, the environmental impact of the MF production is unknown. A consequential life cycle assessment was conducted to compare the impact of three different MFs – aerobic heterotrophic bacteria (AHB), a consortium of microalgae and AHB (MaB), and purple non-sulfur bacteria (PNSB) – to that of commonly used CFs and OFs. The impacts of MFs on human health are comparable to those of fishmeal and green manure, but exceed those of CFs and horn meal, while being 42-72 % lower than for soybean meal. Regarding ecosystem quality, the impacts of MFs and CFs are comparatively low – for AHB and PNSB even negative –, while green manure's and soybean meal's impacts are over 90 % higher. AHB and PNSB have the highest impacts on resource depletion, while MaB scores similarly to other CFs and OFs. The choice of fuels for energy production has a big impact on the results. If waste heat is reused instead of consuming fuels (e.g. in industrial symbiosis systems), currently underexploited MFs would become high quality, low impact organic fertilizers.

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New composting technology as a potential tool for valorizing agri-food wastes into compost and liquid nitrogen fertilizer

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Compost application is one of the main tools to improve soil biodiversity, maintain soil fertility and sustainable food production. Despite the benefits of composting, existing farm-level traditional composting techniques cause substantial ammonia and GHG (N_2O, CH_4) emissions, which could potentially surpass the essential benefits of composting and compost application in the long term. To reduce the environmental impact and improve farm resource efficiency, a company developed a new automated composting drum which can turn organic wastes into compost and liquid nitrogen (N) fertilizer within 7-10 days without external chemical application. While the technology has several advantages, the compost quality and its potential to improve soil fertility need to be evaluated. Given the short retention time, we hypothesized that the compost may not be completely mature and could result in net immobilization of the native N in the soil solution.

To test the hypothesis, we set up an incubation experiment with sandy soil mixed with the new compost (NewComp) and a standard windrow compost (WrComp) both made from organic vegetable wastes. Compost was applied at a rate of 20 t DM ha^{-1}, and a commercial organic fertilizer (OF) at a rate of 6.5 t DM ha^{-1} which is equivalent with the total N applied with the NewComp compost. The moisture content was adjusted to 50% water-filled pore space. Three replicates were destructively removed after 0, 7, 21, 35, 49, 70, and 91 days of incubation in a chamber at 21 ^{0}C and analyzed for mineral N and the soil microbial enzyme, dehydrogenase, activities. A phytotoxicity assay was also conducted using Cress (*Lepidium sativum*) as a test plant in a separate experiment.

The result showed that the NewComp compost has a high C:N (29.5:1) and NH_4^+:NO_3^- (34:1), indicating that the compost is still in the active decomposition stage. Furthermore, NewComp compost resulted in significantly higher net immobilization during the 90 days incubation experiment. On the other hand, the dehydrogenase activity was significantly higher (up to two-fold) in NewComp compost compared to the unamended control, WrComp and OF for 90 days showing that the compost has a substantial potential to improve the soil microbial activities. The phytotoxicity test showed that the NewComp compost could be mixed with soil up to 50% without significantly affecting germination. Further studies are needed to reduce the net N immobilization effect of the NewComp compost.

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Sewage sludge and its value-added products for nitrogen circular economy: Opportunities and challenges

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The global production of waste is estimated to be 3.5 million Mg each day with projections to be doubled and tripled by 2050 and 2100, respectively. Utilization of sewage sludge through circular economy approaches offer a valuable and sustainable sewage sludge management. Sewage sludge has witnessed a profound transformation from being treated as a waste that affects society towards being regarded as a value-added product that may be utilized to generate energy and used to fertilize agricultural production systems, both as a source for the recovery of key nutrient elements. Approximately 50% of sewage sludge is added to agricultural soil in the European Union whereas 28% is being incinerated and 18% ends up in landfills. Presence of macro-nutrients (N, P & K), micro-nutrients and organic matter makes sewage sludge a highly viable option alternative and/or supportive of mineral fertilizers in agricultural production. However, sewage sludge contains a range of harmful contaminants such as organic (dioxins along with polychlorinated biphenyls, pharmaceutical residues, pathogens, and other per-fluorinated surfactants) inorganic (heavy metals) toxicants, which limit the use of sewage sludge as fertilizer. Moreover, the deleterious effects of heavy metals and/or organic pollutants become more magnified during the sewage sludge pretreatment and dewatering stage. Thermal treatment methods can recover energy and eliminate toxicants but can destroy valuable nutrients. Pyrolysis has appeared as a potential and cost-effective alternative method of managing sewage sludge that converts sewage sludge into biochar and biochar-compost mixtures. Sewage sludge biochar not only enhances soil fertility and soil health, but also tends to minimize greenhouse gas emissions and combat global warming. Biochar improves microbiome, soil pH, soil organic matter, soil fertility, moisture retention, soil aggregate stability, and carbon sequestration. Value-added products from sewage sludge includes biochar, biochar-compost and biochar-organic-inorganic fertilizer mixtures with a view to improve nitrogen recovery and subsequent fertilization of the soils. Thus, sewage sludge biochar has great potential in nitrogen, and also phosphorus circular economy. However, scalability of biochar production from sewage sludge, societal perception on the use of sewage sludge biochar, socio-economics costs and legislative framework remains the biggest challenge for nitrogen circular economy from sewage sludge and its value-added products.

Production of Smart Biofertilizers from recovered nutrients: a step forward to turn WWTPs into biofactories

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Environmental sustainability is a major goal for 21st century and high demand is being put for upgrading wastewater treatment plants (WWTP) into Biofactories to address the recovery of nutrients (which deals with United Nations Sustainable Development Goals 6 and 11) such as phosphorus (P) and nitrogen (N) to be reintegrated in the value chain as fertilizers. The current environmental situation grows more critical every day and new and more effective fertilizers are required to keep up with production rates. In this scenario appear the Smart Biofertilizers (Smart BBFs). A new kind of fertilizers characterized for their purpose to go beyond the classic objective of providing nutrients. These new fertilizers pretend to increase nutrient uptake and bioavailability as well as soil health by including plant growth biostimulants.

In order to tackle the production of this Smart BBFs from recovered nutrients from WWTP the WalNUT project (Horizon 2020) was created. Its aim is to increase the circularity of the nutrients reducing the use of non-renewable components in their production. In this framework, different technologies for waste valorisation are going to be demonstrated at lab and pilot scale. One of them is the application of a treatment train based on ion exchange with zeolites and a hollow fibre membrane contactor for nitrogen recovery as ammonium salts from reject water. This treatment train offers the possibility to recover nitrogen with a low energy input, high ammonia selectivity and efficiency as well as avoiding the presence of heavy metals or organic micropollutants in the recovered fertilizer. Furthermore, the process allows to produce fertilizers on demand selecting nitrogen, phosphate, or sulphate salts. This bio-based ammonium fertilizer can be blended with recovered struvite forms (struvite, k-struvite or dirty struvite) producing a NPK BBF adjusted to soil requirements. However, to increase the nutrient-use efficiency in the soil, selected species of plant growth bacteria (PGB) are going to be added to the BBF to develop the Smart BBF. In order to choose the most suitable PGB and find the perfect blend, different tests at lab scale are going to be carry out. Finally, with the recipe adapted for a specific soil, some trails in field are going to be developed to demonstrate the agronomic value of the Smart BBF in real conditions. Furthermore, different analysis to validate their security and safety are also included in the project.

Therefore, the results of WalNUT project will demonstrate the potential new markets for the fertilizer industry by including recovered products in their portfolio which non only will be competitive against conventional fertilizers but also will reduce carbon footprint and circularity index.

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Nutrient cycling indicators and their relation with nutrient use efficiency in agro-food systems

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Agro-food systems must become more circular to reduce resource use and emissions to the environment. To accelerate a transformation towards a more circular food system and to guide scientific debate as a driver, clear indicators are needed to express system circularity, and to evaluate impacts of system changes on circularity. Circularity, however, is no goal in itself. Instead, increasing circularity should serve to improve a system's nutrient use efficiency as expressed in its nutrient output/input ratio (*O/I*), thereby reducing emissions. We explore for systems of different complexity how nutrient cycling is related to *O/I*. Measures of circularity already known are the Finn Cycling Index (here *FinnCI*) used in ecology (Finn, 1980); and the Figge Circularity indicator (Figge et al. (2018). The latter (here *FiggeCI*) has been used to describe material flows in the industry-society tandem. For nutrient flows in agro-food systems we introduce a new indicator related to circularity, and refer to it as the 'nutrient use count' (*UseCt*). It expresses how many times, on average, a cohort of nitrogen (N) or phosphorus (P) input passes through the 'top user' compartment in a system, after being imported and before being entirely dissipated in exported products and losses. For an arable system (I), the 'top user' is the crop, for a dairy farm (II) it is the dairy cow, and for a full-fledged agro-food system that includes food processing and the human consumer (III), it is the consumer. We use the region of Flanders as an example of a type III system. In our analysis, we calculate *UseCt*, *FinnCI* and *FiggeCI* for systems of the above types (I, II, III), and show how they are related to nutrient use efficiency *O/I*. Further, effects of system characteristics (internal conversion parameters; and feed import) on nutrient cycling and *O/I* are illustrated for a Dutch dairy farm. We found that *FinnCI* and *FiggeCI* do not respond to feed import, while *UseCt* and *O/I* respond positively. The efficiency by which cows convert feed to dairy products affects *O/I* positively, but affects *UseCt*, *FiggeCI* and *FinnCI* negatively. All of the above indicators, in contrast, respond positively to an increase in the efficiency by which manure N is converted to soil N. In a Dutch experimental dairy farm, N is used 1.08 times and P is used 2.39 times. For a system subject to losses, values of 1 or larger imply that re-use of N and P (i.e. through cycling) compensates for losses. Finally, our results show that caution is required where circularity indicators are used to express the efficiency by which a system converts N and P inputs into useful products.

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Effect of DMP-based nitrification inhibitors and soil pH on nitrifying and denitrifying soil bacterial populations

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Continued N addition in agricultural soils leads to soil acidification, affecting crops yield, soil nitrification and denitrification processes, and the N_2O fluxes derived from both processes. Liming is the most common strategy to reduce soil acidity. A laboratory incubation with a grassland soil at three different soil pHs (4.5, 5.7 and 6.5) was performed during 45 days at a water filled pore space of 75%. The fertilizer treatments consisted on a dose equivalent to 100 kg N ha^{-1} of ammonium sulfate applied alone or combined with the nitrification inhibitors (NIs) 3,4-dimethylpirazole phosphate (DMPP) and 2-(3,4-dimethyl-1H-pirazole-1-yl) succinic acid (DMPSA). An unfertilized control was also included. N_2O emissions and soil N mineral contents were monitored along the incubation experiment. Nitrifying and denitrifying populations were also determined by means of the quantification of the abundance of microbial nitrogen-cycling functional marker genes by qPCR: *16S rRNA* for total bacterial and archaeal populations, *amoA* for ammonium bacterial and archaeal oxidizers (AOB and AOA), and *nirK*, *nirS* and *nosZ* for denitrifier populations. Both NIs demonstrated a higher efficiency reducing soil N_2O emissions at higher pHs. At pH 4.5 nitrification was inhibited, leading to null N_2O emissions coming from fertilizer. Under these conditions, although there is no frame for NIs to reduce emissions, they significantly reduced the AOB population, being N_2O emissions even lower than those of the unfertilized control treatment. At pH 5.7 the application of AS induced a rise in AOB population, increasing N_2O emissions by 20 times with respect to pH 4.5. NIs were able to reduce this emission up to values below the unfertilized control, decreasing AOB population. At pH 7, the induction of AOB due to AS application was even higher, leading to N_2O emissions 45 times higher than in soils at pH 4.5. NIs were capable again to reduce this emission up to values below the unfertilized control by playing a dual role; first, decreasing targeted AOB population, and secondly, increasing non-targeted denitrifier populations bearing *nosZI* gene, as previously described by Torralbo et al. (2017), so favoring the complete reduction of N_2O up to N_2.

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Nitrification inhibitors and soil pH effect on N2O emissions in a cut grassland

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Soil acidity regulates the enzymatic activity of the processes of nitrification and denitrification. Huérfano et al. (2022) have observed that nitrification inhibitors (NIs) 3,4-dimethylpirazole phosphate (DMPP) and 2-(3,4-dimethyl-1H-pirazole-1-yl) succinic acid (DMPSA) showed efficiencies reducing N2O emissions in a ryegrass forage system of 16% and 29% respectively at pH 5.8. This mitigation effect might be optimized bymeans of increasing soil pH. A field assay with ryegrass *(Lolium multiflorum)* was stated where 8 treatments were assayed resulting from the combination of two different soil pH (5.1 and 6.7) and four different N fertilizer treatments: AS (ammonium sulfate 21%) applied alone or combined with the nitrification inhibitors DMPP and DMPSA and an unfertilized control. N2O emissions and soil N mineral contents were monitored. Nitrifying and denitrifying populations were also determined as the abundance of microbial nitrogen-cycling functional marker genes by qPCR: *16S rRNA* for total bacterial and archaeal populations, *amoA* for ammonium bacterial and archaeal oxidizers (AOB and AOA). The nitrification process was more effective under pH 6.7, where soil NO3- content was higher and the effect of NIs maintaining the NH4" soil content during more time was evident. In general, the N2O emissions mitigating efficiency of DMPP and DMPSA was similar. Under pH 5.1, the efficiency of both NIs reducing N2O emissions was around 15-17%, whereas at pH 6.7 this effect was increased up to 40-45%. Neither soil pH nor NIs application led to significant changes in total soil bacterial population, while total archaeal population was lower under pH 5.1 in comparison with pH 6.7. In general, AOB abundance in the fertilized treatments was higher at pH 6.7, supporting the principle that soil acidic conditions do not favor the nitrification process. Nevertheless, when soil water content was not favorable for nitrification, AOB abundance did not increase in response to the application of AS. When NIs were applied, the AOB population was even lower than in the unfertilized control. Even though AOA are usually more abundant in grassland soils, as in this experiment, AOA, unlike AOB, showed no response to the application of AS at pH 6.7. These results suggest that AOA are not contributing into a great extent to N2O emissions. When DMPSA was applied at soil pH
6.7 a lower AOA population was sometimes observed.

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Unveiling of genetic factors regulating nitrogen uptake and utilization in wheat (*Triticum aestivum* L.)

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In Pakistan, wheat crop production was 27 million tons, and the total area planted was 9.2 million hectares. A huge amount of nitrogenous fertilizer is used for wheat production. Wheat output must expand by at least 50% by 2050 to fulfill rising population demands, which will require further N fertilization. To reduce the waste of expensive nitrogen (N) fertilizers, high nitrogen-use efficiency (NUE) is required for sustainable crop production and yield enhancement and to reduce N pollution caused by excessive use of N fertilizers. Nitrogenous fertilizers account for more than 75% of total fertilizer consumption. An experiment was carried-out at National Institute for Genomics and Advanced Biotechnology, National Agricultural Research Center, Islamabad using a diverse collection of 455 genotypes collected from Ayub Agricultural Research Institute (AARI), Faisalabad. Root system architecture (RSA) was evaluated to understand the role of two nitrogen treatments (50% & 100% of recommended dose) on root growth and development. Wheat plants were grown in PVC pipes using completely randomized design (CRD). Roots of each genotype were taken from each replicate and spread on black sheet with the help of toothpick to visualize the primary and lateral roots clearly. Roots were imaged by a high resolution digital camera and a scale parallel to these roots. Roots related parameters were analyzed by importing the image on ImageJ smart root, and rhizovision Software. Genetic variability was observed in this large population and some genotypes showed variation in primary root length, root density and lateral root number under 50% N treatment. Some genotypes showed extensive RSA while others showed weaker RSA at same N level. This phenotyping of root system in large population is promising to investigate root traits to be characterized for high NUE in wheat under various N regimes.

Keywords: Germplasm, Root system architecture, Nitrogen utilization efficiency, Rhizovision

Nitrogen use efficiency of wheat as affected by variable potassium sources and nitrogen levels

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For sustainable wheat growth and yield nitrogen (N) and potassium (K) are considered as the integral components. Nitrogen is differentially regulated from root absorption to accumulation in grain during all phenological stages. N availability is highly influenced by K because it competes with ammonium binding sites in soils and play role in electrochemical balance for nitrate, ultimately facilitating N uptake. Potassium also plays a significant role in N redistribution from leaves to grain and the production of protein in the grain. Keeping previous literature in view, the present study has been designed to check the effect of different forms of K fertilizers on N use efficiency of wheat. A pot experiment was conducted at Old Botanic Garden, University of Agriculture, Faisalabad. Treatments were applied as two levels of N i.e., 100 % and 75% of recommended with the combination of three K sources applied at the rate of recommended fertilizers keeping a control with no K fertilizer application. Urea was used as N source, the single superphosphate (SSP) was used as P sources, and sulfate of potash (SOP), muriate of potash (MOP), and polyhalite were used as K sources. A completely randomized design was used. The results of this effort explain the overall good response of 75% of recommended level of N for all growth and morphological parameters whereas a non-significant relation between the treatments has been observed for photosynthetic yield (YII), number of tillers, chlorophyll contents (SPAD), photosynthetically absorbed radiation (PAR). Concerning N use efficiency and N content in root, shoot and grain, a non-significant relation between treatments, respectively, was observed. With respect to potassium sources MOP and SOP have proved more responsive with 75% of N level. It shows that use of MOP and SOP along with N enhances NUE and about 25% N fertilizers can be saved using K as above-mentioned K fertilizers.

Keywords: Nitrogen use efficiency, Potassium, Wheat, Polyhalite

The role of biological nitrogen in plant nitrogen nutrition on sod-podzolic soils of Russia

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Long-term studies on sandy and coarse loamy Sod-podzolic soils of the Vladimir Region demonstrate the potential of legumes as a biological source of nitrogen: the results of 42 field experiments show that the greatest yield of nitrogen is achieved by perennial legumes: clover, yellow melilot *(Melilotus officinalis, L.),* and lupins. The total biomass of these crops amounted to 11.7-18.5tonne dry matter/ha, of which 40-56 per cent was roots; on average, root residues contributed 6.3t dry matter/ha/yr and 131kgN/ha/yr. Annual legumes are less productive. Annual lupin yielded 9.4t dry matter/ha and 4.7t dry matter/ha and 88kgN/ha was left in the soil as crop and root residues but, on average, the root residues of annual legumes contained only 29 per cent of the nitrogen accumulated in the total biomass, compared with 48 per cent in perennial legumes; so the intake of nitrogen with the roots of annual legumes was 2.6 times less. Red clover has the highest nitrogen-fixing capacity (263kgN/ha/year), followed by perennial lupin and yellow melilot; on sandy Sod-podzolic soils, lucerne is inferior to clover in its nitrogen-fixing capacity; of the annual legumes, the largest amount of nitrogen was fixed by annual yellow lupin but even this is only half that fixed by clover. In order of the amount of nitrogen fixed (kgN/ha/yr), the performance of the studied crops was: red clover with timothy over two years – 168; red clover over one year – 163; white clover – 153; perennial lupin – 139; peas for green fodder – 138; serradella *(Omithopus sativus, L.)* – 118; lucerne over one year – 114; peas for grain – 106; fodder beans – 104; vetch and oats – 70; peas and oats – 53 (Lukin 2018). According to Kokorina and Kozhemyakova (2010) the potential nitrogen fixation by legumes can reach 550kgN/ha/ yr, and the coefficient of nitrogen fixation 91 per cent.

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Linking root traits and N_2O emissions from grassland soils

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Grasslands, as one of the main global ecosystems, are under pressure by global changes and anthropogenic activities due to the increase demand for food production, and to deliver concomitant ecosystem services via sustainable management intensification. These ecosystems has been a source of greenhouse gas emissions especially nitrous oxide (N_2O), a potent ozone-depleting gas. It is therefore crucial to identify ways to mitigate N_2O emissions from intensive grasslands without compromising high quality food supply. Studies have shown that specific plant species combinations with high trait dissimilarity were particularly effective at reducing N_2O emissions, and the effect of individual species could be linked to specific traits related to the plant's nutrient acquisition strategy. We explored spatial root complementarity effects on N_2O production-consumption throughout the soil profile and on plant N retention dynamics in two grasses, two legumes and two forbs, and a six-species mixtures. We measured soil N_2O concentrations at depth using a unique diffusion probe that can be installed near flux sampling points at depth (5, 10, 20 and 30 cm) with minimum disturbance of the soil profile. Soil samples were taken weekly for soil biogeochemical analyses, leaf samples were taken at the beginning and at the end of the experiment to measure leaf traits, and roots were collected at the end of the experiment to measure root biomass and traits at two different depths. The results are still being analysed, but the preliminary results already show differences of N_2O in the profile.

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Agro-ecological validation of an organic fertigation protocol in areas vulnerable to nitrate contamination

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The impact of the application of a fertigation protocol with natural origin fertilizers on a lettuce cultivation cycle was evaluated by measuring of physiological parameters, soil physical-chemical and microbiological characteristics, crop yield and quality and of the N use efficiency, without there being applications of synthetic inorganic fertilizers. The experimental plot was located in zone 1 of the Mar Menor environment (Murcia, Spain) and soil volumetric water content sensors at two depths (25 and 90 cm) were installed.

The evolutions of gas exchange and nutrients at leaf level throughout the vegetative cycle indicated that plants reached satisfactory nutrition, physiological activity and water status.

Soil samplings at different depths indicated that, after the crop cycle, the organic fertigation protocol i) maintained the levels of soil total organic matter in ranges considered normal, ii) increased the total content of K (20% at 20 and 90 cm) and Mg (17% at 20 and 90 cm), iii) reduced the content of NO_3^- (52, 55 and 68% at 20, 60 and 90 cm, respectively) and PO_4^{-3} (100% at 20 cm), iv) decreased the soluble content of P (55% at 20 cm), K (42 and 37% at 60 and 90 cm) and Cu (44% at 20 cm), v) affected slightly the soil microbial biomass, soil respiration and enzymatic activity, although the levels obtained continued to be considered normal.

The quality parameters and maturity indicators of the lettuce indicated that all the harvested pieces were catalogued with an optimal state of maturity. In addition, the lettuces comfortably complied with Regulation (EU) 1258/2011 *regarding the maximum content of nitrates in food products*. The yield was 29277.3 kg ha^{-1} and the agronomic use per kg of lettuce was 82.6%. The δN^{15} values of irrigation water, fertilizers, plants and of soil at the beginning and the end of assay indicated a good degree of N use efficiency in the agricultural system. The N use agronomic efficiency was 982.7 $kg_{lettuce}$ kg_{N-1}. The extractions of soil N and NO_3^- (soil residual or from the irrigation water) by the crop were 21.9 kg_N ha^{-1} and 3.7 kg_{NO3} ha^{-1}, respectively, in one crop cycle. Finally, net economic yield of the farmer, taking into account income and expenses, was acceptable. Therefore, the ecological cultivation of lettuce was considered viable from the agronomic, economic and environmental point of view in an area vulnerable to nitrate contamination.

Impact of Nitrogen Addition on CO_2 emissions at Different Stages of Plant Residue Decomposition

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Nitrogen (N) addition likely to change soil C storage through stabilization of soil C, influencing microbial activity, plant litter decomposition and losses of C especially soil respiration. Less or high dose of N fertilizer application with respect to time probably impact content and quality of soil organic carbon (SOC). Under varied management practices variable impacts (neutral, negative or positive) of N fertilization on residue decomposition and SOC dynamics have been reported. The current study was aimed to evaluate impact of N addition at different stages of two distinct plant residue decomposition on soil microbial activity and soil carbon. A laboratory incubation experiment was carried out using 50 g soil in incubation jars along with two different quality residues i.e. wheat and rice residues (10 g residues kg^{-1} of soil) and one control without residues was also maintained. Nitrogen (132 mg kg^{-1} of soil) was added at two stages of residue decomposition i.e. (1) at the time of residue addition and (2) after 15 days of residue decomposition. The soil CO_2 emissions were measured after 1, 2, 5, 10, 15, 25, 35, 45 and 55 days of incubation. After 55 days of incubation, soil microbial biomass and extracellular enzyme activities were determined. Results showed that with addition of crop residues (wheat and rice) there was significant increase in cumulative ($C\text{-}CO_2$) as well as microbial biomass carbon (MBC) and dissolved organic carbon (DOC). The N addition at 1st day reduced cumulative ($C\text{-}CO_2$) emissions in rice residues but enhanced cumulative ($C\text{-}CO_2$) emissions in wheat residues. While, N addition after 15th day enhanced cumulative ($C\text{-}CO_2$) emissions in wheat residues but non-significant by rice residues. The MBC reduced in both residues types by 1st day N addition while non-significant by 15th day N addition. The DOC reduced in wheat residues by N addition at both stages and enhanced in rice residues by 15th day N addition. Enzyme activities increased significantly with the addition of crop residues except chitinase which showed significant decline by wheat residues. While, rice residues significantly enhanced all enzymes activity except acid phosphatase, that was non-significant. The β-glucosidase activity enhanced and chitinase activity declined by N addition at both stages in rice residues and non-significant in wheat residues. The acid phosphatase enhanced in both residues by 1st day N addition and declined in 15th day N addition. The leucine aminopeptidase activity reduced in wheat residues by N addition at both stages and enhanced in rice residues by 15th day N addition. Residue type and addition of N at different interval of residue decomposition has significant impact on cumulative $C\text{-}CO_2$ emissions, while MBC and DOC increased by residues and decreased by adding N initially and no significant impact by N addition in partially decomposed residues. The addition of residues as well as N at different stages have varying impact on soil extracellular enzymes activity.

Biochar production from forest waste as a source of nitrogen and phosphorus

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Biochar is charcoal made from plant, animal, or human waste biomass that improves soil function and reduces CO_2 emissions caused by the natural degradation of biomass. Biochar produces complex nitrogen forms, and their ability depends, among other factors, on the pyrolysis temperatures used during the process of biochar production. Moreover, the pyrolysis temperature can also modify the phosphorus concentration in biochar. In regions like Galicia (NW Spain), where 65% of the land is forest land, biochar could be produced from forest waste following the circular economy and bieconomy strategies of the European Commission. However, there is a lack of knowledge about the potential of forest waste as a resource to produce biochar. The objective of this work was to evaluate the total concentration of nitrogen and phosphorus in biochar produced from the waste of conifers (*Pinus radiata*, *Pinus sylvestris*, *Pinus pinaster*) and broadleaf (*Betula alba*, *Quercus robur* and *Castanea sativa*) trees under different pyrolysis times (30 minutes, 1 hour and 2 hours). In 2021, forest materials were collected in forest plantations of Galicia (NW Spain) established with conifers and broadleaf trees. In each tree species, dry leaves, green leaves and branches with a maximum diameter of 0.5 cm were manually separated and each tree fraction was pyrolyzed separately under no oxygen conditions at 300°C for 30 minutes, 1 hour and 2 hours. At the laboratory, the total concentrations of nitrogen and phosphorus in the biochar were determined. The obtained data were analysed with ANOVA and the LSD test. The results showed that the total concentrations of nitrogen and phosphorus were generally higher in the biochar produced from *Quercus robur* compared to the other tree species. Moreover, the total concentrations of nitrogen and phosphorus were generally higher in the biochar produced from green leaves compared to dry leaves and branches probably because most of the nutrients were transmitted to the green leaves for sugar processing. The total concentration of phosphorus in the biochar was also modified by the pyrolysis time, decreasing as the pyrolysis time increased. However, the total concentration of nitrogen was not significantly modified by the pyrolysis time. Therefore, in biochar production, it is important to take into account the starting material, but also the pyrolysis time that can modify the capacity of the biochar as soil amendment and fertiliser.

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Impact of different nitrogen rates on ammonia volatilization and nitrogen use efficiency of wheat (*Triticum aestivum* L.)

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Ammonia (NH_3) volatilization from agricultural systems is contributing to atmospheric reactive nitrogen (Nr), lowering air quality and human health. Ammonia emissions reduce N uptake efficiency and have a negative impact on agricultural sustainability. A field experiment was conducted by using randomized complete block design (RCBD) having four treatments (0, 100, 134, 168 kg N ha^{-1}) with four replicates to determine the NH_3 volatilization and N use efficiency (NUE) in wheat crop. Acrylic chamber was used to capture the volatilized NH_3 from soil surface. and was determined after each fertilization event at 1, 2, 4, 7, 10 days' time intervals. The results indicated that NH_3 volatilization loss increased linearly with increasing the rate of N. In each split, NH_3 volatilization was increased in 168 kg N ha^{-1} per plot. The peak time interval of NH_3 volatilization were between 2 to 4 days after each fertilization event and after that it started to decline with passing days. The ratio of NH_3 volatilization losses to the applied N ranged from 18.02 to 50 % with different N application rates. Cumulative NH_3 losses in (100, 134, 168 kg N ha^{-1}) plot was (197%, 278%, 346%) respectively, as compared to control. The maximum grain yield (3.56 t ha^{-1}) was observed in (168 kg N ha^{-1}) plot and plant biomass was non-significant between 134 and 168 kg N ha^{-1} treatment. NUE was (9.05, 11.79, 11.66 %) respectively, in (100, 134, 168 kg N ha^{-1}) treatments. For sustainable wheat production and N management, NH_3 volatilization losses should be managed by appropriate N application using appropriate strategies. Furthermore, agronomic practices should also be managed to avoid the losses and for sustainable N management.

Keywords: Ammonia, Volatilization, NUE, wheat

Modeling the effects of climate change on nitrogen use efficiency (NUE) of wheat in arid and semi-arid environments

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Nitrogen (N) is, no doubt, an essential key element without which it is not possible to survive on this earth if we only consider its role in food production. However, its judicious use in crops to enhance yield with high N use efficiency (NUE) is crucial for sustainable environmental management. Two years (2020-21 and 2021-22) field experiments on wheat have been conducted for optimization of N fertilizer rate and to achieve higher NUE using randomized complete block design (RCBD) with four replications. Four N fertilizer rates, no N fertilizer (control), 75% of recommend fertilizer (RF), 100% of RF and 125% of RF were used as treatments. Data on crop phenology, growth, yield, soil, and weather attributes were collected. Fisher's analysis of variance technique was used to analyze the collected data. Results show that biological and grain yield were increased when we applied incremental N to crop as compared to control (No N). The agronomic parameters such as plant height and number of tillers were not affected, however, plant biomass increased in N fertilized fields as compared to control. Maximum grain yield was observed where 125% RF was added. The shoot, grain and husk N concentration was increased in N fertilized treatments as compared to control and maximum was observed in 168 kg N ha^{-1} plot. A significant decrease in yield was observed in the second year 2021-22 due to rise in elevated temperature in March 2022. The overall yield was declined to 35-45% in 2021-22 as compared to previous year 2020-21. NUE was maximum in 100% RF plot in both years 2020-21 and 2021-22, respectively (14.53 and 11.79). But there is non-significant difference in 125% of RF as compared to 100% RF (13.10 and 11.66). To investigate the threats of this changing climate change scenarios and its effects on crop production we have linked this study to crop modeling part for sustainable N management and maximizing NUE of wheat. The data collected during these experiments will be further used to calibrate the wheat model in the shell of Agriculture Production System sIMulator (APSIM). The model will be further run with projected climatic data for late century scenarios (2070-2099) under RCP 8.5 to simulate the effect of climate change on NUE of wheat in both arid and semi-arid environment.

Keywords: Climate change, NUE, APSIM, Future scenario, Arid and semi-arid

High animal comfort and low emissions in a new housing system for pigs

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Introduction

The objective of the research work was the development of a pig production system that drastically reduces environmentally and climate-relevant emissions, optimises N-efficiency and at the same time meets the socio-political requirements for animal-friendly farming. The working hypothesis is that these requirements cannot be met with the current technologies for pig housing systems based on liquid or farmyard manure systems.

Concept of the housing system and manure removal system

The housing system is characterised by a symmetrical structure of 23-25 m width and an interior comfort zone that allows heating and cooling. Faeces and urine are separated in the barn with a scraping or robot system. The separated urine is stabilised in the barn with either acids, leaches or sysnthetic urease inhibitors and is quickly removed from the barn. Practical observations show that the housing system is very well adapted to provide the fattening pigs with an animal-friendly environment and to support the animals in their inborn cleanliness behaviour. The reversal of the functional areas, which can be observed in most cases by creating defecation wallows in the comfort zone, can be avoided.

Laboratory tests on stabilization of urea and precipitation of nutrients in urine

Laboratory tests have shown that the addition of acid (up to a pH of 2.5 with H_2SO_4) or leach (pH 12.3 with $Ca(OH)_2$) completely suppresses urea hydrolysis over the entire 30-day experimental period. The alkalinisation of native urine resulted in precipitation rates of 100 % for calcium, 68 % for phosphorus and 73 % for magnesium. When acidified, all nutrients remain dissolved.

Emission abatement

The inhibition of urease as well as the induction of nutritional element precipitation reactions can be controlled very effectively. The production of a low nutrient effluent is feasible. Accordingly, it can be expected that ammonia emissions can be reduced by 70 % or more with this integrated manure management compared to fully perforated housing systems. By largely preventing fouling processes, methane emissions will presumably be reduced by 90 % and odour emissions by 50-70 %.

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Nitrification potential and N_2O emissions assessment from processed slurry under controlled conditions.

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Nitrification process in soil is involved in N cycling influencing the extent to which N can be lost from soil. As a potential N loss pathway, nitrification process and nitrifying microorganisms can be affected by N input derived through different amendments. In this study, N_2O emissions and potential of soil nitrification were measured at day eight following application of 100 kg N ha^{-1} of four types of organic fertilizers to grassland. These consisted on cattle slurry, liquid fraction, solid fraction and compost. The experiment was carried out under controlled conditions in a climatic chamber (21°C). Soil depth was 7.5 cm and an average water content of 26.7%. The highest N_2O emissions and nitrification potential were observed in the solid fraction. All the other treatments presented a nitrification potential close to 4 mg N kg^{-1} day^{-1}, twice that of control grassland with no fertilization. Compost application resulted in significantly lower N_2O emissions than the slurry and liquid fraction, with 17 and 19% respectively lower emission. Compost being an N-stabilized fertilizer, N_2O emissions after compost application are significantly reduced, as reported by Flavel and Murphy (2006). Hence, the different nitrogen availability of the amendments can cause emissions to vary greatly. Thus, composted manure can be considered as a mitigation strategy to decrease N_2O emissions.

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Soil nitrogen modelling in grasslands of the north of Spain under conventional and rotational grazing scenarios

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Grassland soils are a large soil carbon pool that can be at risk of being lost under inadequate management. If management practices are promoted to increase soil C storage, grasslands have the potential to help alleviate greenhouse gases emission. Previous studies have reached different types of conclusions about rotational grazing, either increasing soil nitrogen stocks (Mosier et al. 2020) or observing higher N2O emissions (Jackson et al. 2015). In this study, we compared three different types of grassland management (mowing (M), conventional grazing (CG) and rotational grazing (RG)) in relation to nitrogen stock and N_2O emissions. For this purpose, we calibrated PaSim model with observed data from grasslands in northern Spain under Atlantic climate. The grazing scenarios were operated on 30 ha of grazed grasslands with the same total number of animals. However, livestock unit densities and grazing periods varied between rotational and conventional systems. The results showed that both grazing systems emitted less of 3.92 µg N m^{-2} h^{-1} than mowing management. However, over 26 years, CG management accumulated at 60 cm of soil depth 0.0243 t N ha^{-1} more than RG, presenting also lower N_2O emissions ($\Delta N_2O_{RG\text{-}CG}$ = 4.06 µg N m^{-2} h^{-1}). Nitrogen retention may be lower in the RG, because when many excreta are discharged to the soil in a short time, leading to leaching and high levels of nitrogen mineralization, which could explain the higher N_2O emissions. It should be taken into account that the uncertainties of the results are high since the PaSim model has not been calibrated for pastoral systems in rotation, since high animal densities in short periods of time can produce changes in the dynamics of the variables used by the model that are not taken into account in conventional systems.

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Greenhouse gases emission as affected by dairy manure fall-applied to a Silvopastoral system based on Pecan in Argentina

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The management of agricultural resources and wastes increases system circularity, minimizing greenhouse gases (GHG) emissions and opening a new path for the high-efficiency and environmental-friendly production, optimizing the energy-water-food nexus approach. Silvopastoral systems (SS) are circular since they incorporate woody perennial plants along with grasses and animals, increasing nutrient cycling and beneficial interactions between the components. Pecan (*Carya illinoinensis*) has been little studied under SS; however, we do know that pecan nut growth and quality are sensitive to nitrogen (N) addition, a nutrient highly circulated by the SS. Adding N derived from poultry or cattle manure to pecan orchards increases nut yield, but we know little about its effect on GHG. Thus, this study aims to assess the GHG emissions after the application of dairy manure to pecan under a SS. Our experiment was conducted at the INTA Balcarce Research station (37°45'48.96''S; 58°17'26.49''O), Argentina, from April to June 2022 (late fall) in a nine years old SS pecan-based. The pecan orchard has a design of alley cropping with single tree rows, where pasture species are located between the Pecan rows. The treatments consisted of the application of dairy manure in the trees (MT), the alley pasture with no manure application (NMP) and no manure application in the trees (NM), with four repetitions each one. The soil had 2.68% of carbon (0-30 cm) and the dairy manure applied had 1.8% of N. The GHG were sampled with the static chamber method 3 consecutive days after manure application. We used 20 mL plastic syringes to withdraw the air after 0, 14, 28 and 42 minutes past chamber deployment. Nitrous oxide (N_2O) and methane (CH_4) were analyzed through a gas chromatograph and the difference among treatments across time was assessed by a multivariate analysis of variance. The peak of GHG emissions occurred in the second day after manure application but we found no significant effect of dairy manure addition. Mean emissions for N_2O were 72.2, 46.5 and 12.25 g N ha^{-1} d^{-1} for MT, NMP and NM respectively. For CH_4, the mean emissions were 32.0, 38.0, and 0.00 MT, NMP and NM respectively. This trend remained as N_2O and CH_4 were converted into CO_2eq emission (MT= 39.2 kg CO_2eq; NM=6.42 kg CO_2eq and NMP=15.3 kg CO_2eq) suggesting that there is little impact on GHG emissions for dairy manure addition to pecan during late fall. Thus, that practice could be effective for farmers, with few impacts in the environment, enhancing SS circularity.

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Integrated approach to estimation of nitrogen use efficiency in intensive dairy husbandry at farm level in the North-West Russia

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The efficient use of nutrients, nitrogen in particular, is a high-priority task of modern animal husbandry for achieving the United Nations Sustainable Development Goals. The study aimed to explore applicability of nitrogen use efficiency (NUE) as an indicator in estimating the reduction potential of nitrogen losses to the environment on dairy farms in the Leningrad Region. This region is leader in dairy farming in the North-West Russia. In 2021, the average per cow milk yield was 9022 kg cow^{-1} yr^{-1}. The study considered three pilot farms, which featured high cow performance, zero-grazing, and a share of 40 to 50% of imported feed in the diets. Farm Gate Balance (FGB) was calculated for these farms by the accounting data acquired during the farms surveys. The farms differed much in the production intensity: N inputs were in the range from 60 to 140 kg ha^{-1} yr^{-1}, and N outputs – in the range from 25 to 40 kg ha^{-1} yr^{-1}. The NUE values for these farms, however, were of small difference – 22% to 27%. This fact revealed a certain difficulty in formal application of FGB indicators for comparative environmental farm assessment, as NUE and N surplus were affected by many interrelated factors.

To refine the decision-making methodology associated with improving environmental performance of a particular farm, we assessed the variation pattern of environmental indicators of a pilot dairy farm with 2,200 head of cattle, including 1,000 cows and 2,276 ha of arable land. The NFGB of the farm was calculated by the data for 2017-2021. While N inputs were in the range of 90.7 to 138.7 kg ha^{-1} yr^{-1} and N outputs – of 29.3 to 41.2 kg ha^{-1} yr^{-1}, NUE was in the range of 26% to 36% and N surplus – of 61 to 103 kg ha^{-1} yr^{-1}. Calculation results showed the essential role of systemic measures for NUE improvement like increasing the own feed production and animal productivity, and reducing mineral fertilisation. In the period under study, the share of purchased feed ranged from 22% to 52%; the milk yield increased from 8770 to 10719 kg yr^{-1}, and the share of livestock products ranged from 50% to 83%.

The measures for NUE improvement of a particular dairy farm were considered with “N input–N output” diagram, which visualised NFGB of the farm and N balances of its four production sectors: crop sector (NUE_{FIELD} was in the range of 62 to 110%), livestock sector (NUE_{STABLE} was in the range of 15 to 20.5%), processing sector ($NUE_{PROCESSING}$ was in the range of 70 to 90%), and manure handling sector ($NUE_{MANURE\ HANDLING}$ was in the range of 70 to 75%). High NUE_{FIELD} values indicated the soil depletion risks and the need for optimising the doses of organic and mineral fertilisation of each particular field. In the manure handling sector, the use of low-emission application machines would enhance the NUE and provide about20% lower mineral fertilisation. The applied approach and the estimation results of “N input - N output” balances of the dairy farm production sectors can be used in monitoring, assessing and managing the environmental performance of dairy farming at different levels.

Hyperspectral imaging for the assessment of mineral nutrition status in peach trees

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The Common Agricultural Policy (CAP) reform in the European Union has set as a remarkable objective the reduction in nutrient losses of at least 50% by 2030. This is expected to lead to a reduction in fertiliser use of at least 20%.

Peach [Prunus pérsica (L.) Batsch] is the most important temperate fruit tree grown in Spain, with 47.7 thousands of hectares grown in 2019 and an equivalent production value over a 380 million of euros.

The nutritional status of peach trees can be addressed based on the mineral analysis of either leaves or flowers. Even though the analysis of flowers anticipates following leaves chlorosis, up to date it has not been possible to develop in site measuring techniques of the mineral composition of flowers, while leaves chlorosis is well adapted to spectral measurements. In most cases chlorosis starts on the youngest or apical leaves, located at the exterior of the canopy affecting all branches in the same way. These characteristics facilitate the inspection of the crop using on-board sensors based on optical responses.

In this study, a trial was carried out at The Experimental Station of Aula Dei (CSIC) on a calcareous soil, with 29-30% total calcium carbonate, 7.4-7.6% active lime, pH in water 7.7 and a clay-loam texture. Thirty-two Caterina peach trees on seven rootstocks were supervised according to the mineral composition of leaves and flowers: K, Ca, P, Mg, S, Na, Al, Fe, Cu, Zn, Sr, Mn and B. Three leaves per tree were considered for hyperspectral measurements, and over 140,000 spectra were extracted for detailed analysis

As main features, the spectra of leaves showed: a) a general increase of reflectance from 500 to 600 nm, with a peak around 550 (associated with the loss of chlorophyll a and b), b) a red-edge displacement to the left, and c) an overall weak decrease of reflectance at NIR range (probably due to the degradation of leave microstructure due to the increase in chlorosis affection). Three nutritional categories could be established using the spectral data base, which may be a valuable tool to design a nutrient management plan that involves a more rational use of fertilisers

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Integrating environmental sustainability efforts across community and university bounds: A case study with Charlottesville City, Albemarle County, and the University of Virginia

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Many entities use environmental footprint tools to help evaluate and improve environmental sustainability. The objective of my research is to build an integrated carbon (C), nitrogen (N), and phosphorus (P) footprint tool to estimate and spatially visualize the footprints of Charlottesville City, Albemarle County, and the University of Virginia. The tool is an addition to the suite of N-print tools by expanding to a community level as well as integrating other indicators (C and P). To create the tool, I have built off of several existing tools, including the Community Nitrogen Footprint Tool (C-NFT) (Dukes et al., 2020) and the Sustainable Indicators Management and Analysis Platform (SIMAP) (Leach et al., 2017). The data gathered to create this tool largely consisted of publicly available datasets on the census block group level for city and county calculations and reported datasets from UVA's carbon and nitrogen footprint tracking efforts. The tool can be used to propose scenarios to evaluate tradeoffs and co-benefits of existing sustainability strategies and additional scenarios. The model can be used to serve as an example of how communities and institutions can work together to improve environmental outcomes by evaluating multiple indicators to assess environmental sustainability.

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The "Atmosphere" pool flows within National Nitrogen Budget for Belarus

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Reactive nitrogen (Nr) emissions cause a wide range of environmental problems. At the same time, nitrogen is critical as a major nutrient for food, fiber and bio-fuel production. Nitrogen budget is an efficient instrument for determining the Nr flows, and provides policymakers with information for developing efficient emission reduction measures.

As the first step of Belarus national nitrogen budget (NNB) construction the nitrogen flows for the Atmosphere pool (AT) were calculated. Assessment was performed for year 2018.

The N flow calculation for the pool Atmosphere combines different methods. The data on emission of NOx, N2O and NH_3 from the economic sectors are taken from the National Reports under CLRTAP and UNFCCC, the deposition and transboundary transport of NHy and NOx is given by the EMEP Source-Receptor-Tables (Norwegian Meteorological Institute 2020).

According to the assessment 280 kt of Nr has been introduced into the Atmosphere pool in Belarus in 2018. Total Nr inflow consists of emissions (180.6 ktNr) and transboundary inflows (99.0 ktNr). Almost 60% of Nr emissions are comprised of NH_3, 24% of NOx, and the rest of N_2O. The transboundary inflows consists of NH_3 and NOx almost in equal proportions. Emitted Nr in form of NO_X mainly results from Energy and Fuels pool (about 95.2% of total NO_X-N), in form of N_2O and NH_3 mainly results from Agriculture Pool (85.7% of total N_2O-N and 91.7% of total NH_3-N).

Total outflow form AT pool, according to assessment, includes 152.0 ktNr of Nr deposited and 86.4 ktNr of Nr transported. 60% of nitrogen are deposited in NHy form and 40 % in form of NOx. There is a difference of 41.3 ktN between total atmospheric Nr inflow and outflow. Excluding N2O, which is not deposited and for which none of the models include imports or exports, the difference between total inflow and total outflow is reduced to 11.369 ktN, or about of 4% of the total atmospheric Nr turnover.

According to assessment using mass balance approach, about 42% of the national NH3 and 19% of the NOx emissions are redeposited in Belarus. Overall, Belarus NNB for AT pool has a close to equilibrium ratio of exports and imports of the total Nr with slide shift to import (transport inflow is 115% of transport outflow), while for the oxidized Nr imports significantly exceeds exports (transport inflow is 196% of transport outflow) and for the reduced N transport inflow is 79% of its transport outflow.

Integrity and potential future development of forests in Germany exposed to atmospheric nitrogen deposition and climate change in Germany

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Outlines of a complex methodology for assessing and classifying forest ecosystem integrity under conditions of climate change and nitrogen deposition are presented. Vegetation and soil data from about 22,000 forest stands from 1961-1990 were used to classify forest ecosystem types. These were linked to the potential natural vegetation and biotope types of Germany, the FFH habitat types and the classification of the European Nature Information System and mapped nationwide. Using 14 indicators for 6 ecosystem functions, historical reference conditions (1961-1990) were quantified for 60 forest ecosystem types. The comparison with current (1991-2010) and potential future ecosystem conditions (2011-2040, 2041-2070) formed the basis for the ordinally scaled classification of ecosystem integrity at the level of indicators, functions and ecosystem types. Projections of expected ecosystem changes were based on dynamic modelling of soil indicators considering climate change and anthropogenic nitrogen deposition for 2011-2040 and 2041-2070. The ordinally scaled classification of the development of ecosystem integrity provides an ecological basis for nature conservation monitoring of habitat types according to the Habitats Directive and for an assessment of ecosystem services. A validation of the methodology for classifying ecosystem integrity at regional level was carried out using the Kellerwald National Park (Germany) as an example. It was found that soil moisture is a particularly sensitive indicator of changes caused by climate change.

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Estimation of Nitrogen budget in the transboundary river catchments of Eastern Europe dominated by agricultural activities

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Agriculture, industry and other human activities have been altering Nitrogen (N) cycling leading to N imbalance at ecosystem and regional levels. This results at numerous environmental impacts on air, water and soil quality, GHG balance and ecosystem functioning. Quantification of N flows at district scale to build joint N budget is an efficient tool for identification of relevant domains to apply mitigation measures. This study aims to develop N budget for the transboundary region in East Europe, embracing Dniester and Prut basins within Ukraine-Moldova-Romania, to assess N flows contribution and impact on the Black Sea.

We conceptualized to distinguish three main categories of N flows within the boundaries of the studied system: input (incoming from elsewhere to the system), output (outgoing to elsewhere from the system) and internal cycle flows (which originate/ produce and consume/ utilize within the system boundaries). We estimated that in 2015 major N flows in the region were associated with animal husbandry (the absolute values of forage used and manure excreted are currently under revision), while only ca. 11% of excreted manure was reported to be reused as fertilizers. Synthetic N fertilisers applied (190 Gg N y^{-1}) formed the second source of N came into the region. Atmospheric N deposited of 145 Gg N y^{-1} was the third largest source. N excretion from humans in rural areas with no sanitation was likely to be significantly higher than N discharged with wastewaters.

Most N was removed from the region with crop yield/ by-products (ca. 303 Gg N y^{-1}) and animal products (under revision). N losses (NO_x+NH_3+N_2O) to the atmosphere from land-based activities were 128 Gg N y^{-1}. Agriculture sector contributed ~63% of total N-gas emissions. N discharge by Dniester to the Black Sea made 26 Gg N y^{-1}. We roughly assessed that ca. 258 Gg N y^{-1} might be emitted as N_2 from the water surface in the basin (data are uncertain but call for special attention!).

Conclusions based on the revised data will be presented in the conference. At the moment one can clearly indicate that N losses are highly uncertain in the region due to their estimations based on unspecific emission factors developed for other regions rather than proved by robust region-specific *in-situ* measurements.

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Nitrogen fluxes due to agricultural activities and wastewater management in Turkey

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In this study, we conducted a trend analysis of major N fluxes produced/consumed in agriculture sector including crop production and livestock breeding as well as nitrogen introduced to environmental reservoirs (sea, rivers, lakes, dams, land, other) as a result of municipal wastewater management implementation (both treated and untreated wastewater) in Turkey. Two separate excel databases are established for both of the agriculture and wastewater sectors. Agriculture sector database comprised each type of crops grown, nitrogen uptake coefficients of crops, N fixation by free-living bacteria, N-fixation by legumes, populations of animals raised, nitrogen production coefficients for different animals and the magnitude of agricultural lands. Total utilized agricultural land was divided into three parts as; 1-total arable land, 2- total land under permanent crops and 3-land under permanent meadows and pastures. In our calculations, sum of 1 and 2 were used as total crop cultivation land. A mass balance for soil due to agricultural activities is conducted and the residual nitrogen (N surplus) was calculated. Four different fertilization intensity analyses were conducted with respect to either only chemical fertilizer or sum of manure and chemical fertilizer applied over both of crop cultivation land and total utilized agricultural land. Wastewater sector included the flowrates of treated/untreated wastewater collected by municipal sewerage system, N content of untreated wastewater, the related N-treatment efficiencies for each type of treatment method and the corresponding flowrates of discharge to different environmental reservoirs from both treated and untreated wastewater in proportional with the flowrates with respect to years in Turkey using earliest available official data. The ranges of data were 1991-2017 for agriculture sector and 1994-2018 for wastewater sector. Results showed that total chemical fertilizer-N consumption followed a variable trend changing between 1104 and 1764 kilotons. Nitrogen fixation by legumes and free-living bacteria found to be 275 and 152 tons respectively as of year 2017. Cattle breeding produced the highest amount of nitrogen (1270 kilotons at 2017) followed by sheep and goat farming (576 kilotons at 2017), poultry raising (140 kilotons at 2017) and other animals (11.4 kilotons at 2017) respectively. Total manure nitrogen production followed a decreasing trend until 2009 and increased after 2009 reaching the value of 1998 kilotons at 2017. Total N uptake by crops fluctuated between 872 - 2011 kilotons. N uptake by plant types grouped under cereals were highest (1721 kilotons in total N uptake of 2011 kilotons at 2017) among the other crop types. N surplus (for total utilized agricultural land) fluctuated between 9-32 kg/ha with a minimum residual N value of 337 kilotons (at 2011) and maximum value of 1282 kilotons (at 1993). Municipal wastewater treatment ratio followed an increasing trend and reached to almost 88 % at 2018 from 19% at 1994 and the total N discharged to environmental reservoirs due to wastewater management doubled (from 60 to 114 kilotons). Almost half of the total 114269 tons of residual N in municipal wastewater (both treated and untreated) was discharged to rivers (54966 tons) and about 38% was discharged to sea.

Surface Modification of Coal and its Application to Mitigate Ammonia Loss from Livestock Manure

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Ammonia (NH_3) emissions from agriculture, the majority of which arise from livestock manure, have caused widespread adverse environmental impacts. Although the application lignite (i.e., brown coal) to animal bedding has been proven to effectively reduce NH_3 loss from intensive beef cattle feedlots, widescale implementation of such technology is limited because the high moisture content of lignite makes the long-distance transportation uneconomical. Thermal air oxidation provides a simple and effective surface oxidative modification method to dewater lignite and introduce acidic functionalities on surfaces of black coal and coal tailings (wastes resulting from washing coal) with high efficiency to increase the NH_3 capture capacity (Zhang et al., 2022a; Zhang et al., 2022b). The addition of dewatered lignite and modified black coal in cattle manure can reduce NH_3 volatilization to a similar extent as the raw lignite and enhance N retention in manure (Zhang et al., 2022a). These findings suggest that modified coal materials are promising alternatives to lignite as additives to animal beddings where lignite is not available and offer potential for mitigation of NH_3 loss in livestock farms, improvement of N retention in manure and development of a circular nutrient economy.

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The National Fertilizer Plan and its implications for nitrogen sustainability in Brazil

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Agribusiness is of paramount importance to Brazil – it employs 38% of the labor force and accounts for about 40% of the volume of exports, which make the country one of the largest producers and exporters of agricultural commodities in the world. In consequence, the consumption of synthetic nitrogen fertilizers in Brazil has been growing substantially over the years (a 1,698% increase between 1970 and 2019), with more than 80% of the total consumed being imported. In response to this scenario, the recently launched National Fertilizer Plan (NFP) aims to strengthen policies to increase the competitiveness of the internal fertilizer industry, reduce external dependence, and increase the participation of Brazilian agribusiness in the international market (Decree nº 10.991/2022). Unfortunately, among the five strategic objectives listed in the NPF for the period from 2022 to 2050, none of them directly refers to the environmental impacts caused by the unsustainable use of N-fertilizers. This is a very problematic situation, as fertilizer consumption is one of the most relevant indicators that have determined the weak-to-basic level of sustainability of nitrogen management in Brazil (Cunha-Zeri et al., 2022). In this study, we analyze the impact of the NFP on nitrogen management in the country and especially on the development of a national action plan to reduce nitrogen waste, as outlined by the 2019 Colombo Declaration. We also discuss the inclusion of potential policy strategies in the context of the NFP objectives, especially through its integration with the 2009 National Plan on Climate Change.

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Assessment of N mineralization from pelletized and non-pelletized composts through an incubation experiment

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Composting allows to obtain a stabilized fertilizing material, free of pathogens and weed seeds and with the humification of the organic matter. However, the N mineralization in the soil, which is important to the crop's uptake, can be affected not only by the sources of the composted organic materials but also by the physical form of the compost. The stability of the pellets is an important factor of their quality since it allows them to remain in their physical form during the transportation and application. How the pellets stability affects the N availability for crops is still poor understood. The objective of this work was to evaluate the N mineralization after compost addition to soil though an incubation experiment under controlled laboratory conditions for 7 weeks. The composts used were obtained from two different sources: pig slurry (CS) or the dry fraction of the digestate obtained after the anaerobic digestion of the pig slurry (CD). These composts were in two different physical forms: non-pelletized (NP) and pelletized (P). The soil used in the experiment was a dystric Regossol. The experimental design was completely randomized with 6 treatments each one with 3 replicates. The treatments were: 1) control without fertilization (C); 2) mineral N fertilization (Ni); 3) non-pelletized compost from pig slurry (CS-NP); 4) pelletized compost from pig slurry (CS-P); 5) non-pelletized compost from digestate (CD-NP); and 6) pelletized compost from digestate (CD-P). N fertilization was done at a rate equivalent of 340 kg N ha^{-1}. The temperature of incubation was 28 ºC and the soil was kept at 75% of field capacity. The experiment started at 05/23/2022, and a soil sample was taken weekly from each treatment and replicate. The results indicate that the NP and P composts, increased the mineral N in the soil after 21 days of incubation with respect to C. The treatments from CD showed the highest increases in mineral N (17.2 -NP and 18.9-P mg kg^{-1} respectively), while the treatments from CS showed lower increases (4.1-NP and 7.4-P mg kg^{-1} respectively). Nitrate correspond to the main N mineral form at 21 days, with 64% for C and 95% for CD-NP and CD-P. As a preliminary conclusion the results suggested that the sources of organic materials used for composting affected the N mineralization. Moreover, the pelletized composts showed higher increases in mineral N with respect to non-pelletized treatments.

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Conclusions

Halving nitrogen waste by 2030: a socio-political challenge based on sound science

This XXI[st] edition of the International Nitrogen Workshop entitled "Halving N waste by 2030", hosted by the ETSIAAB, Universidad Politécnica de Madrid, and organised by the CEIGRAM and INIA-CSIC, brought nearly 300 participants together, the majority of them in person, and received **nearly 300 contributions from authors from 40 countries**, presented in this book. This edition hosted sessions dedicated to research at the level of agro-food systems, and also around public policies and their costs and benefits, thus making ample room for systemic approaches and social sciences. We summarise below the key conclusions drawn by the session chairs from all the keynotes, roundtables, and regular and special sessions of this meeting.

The keynote by Mark Sutton introduced the "**N waste**" concept, defined as the waste of resources and money from anthropogenic reactive N flows, and demonstrated the possibility of halving N waste by 2030 through both technical and structural measures. The ongoing increase in the price of inputs since 2021, such as synthetic fertilisers, could accelerate the implementation of measures in this direction. The **regular sessions** that followed shed light on the links between the different scales and the methodological complementarities for exploring the reduction of N waste in agricultural systems and surrounding ecosystems.

At the **cropping system scale**, Xin Zhang and Laura Cárdenas argued that it is important to harmonise definitions and estimates of N use efficiency at all levels and to clarify national greenhouse gas inventories in order to better adapt measures to reduce N pollution and estimate the contribution of agricultural practices to climate change. Nandula Raghuram presented the state of research on rice breeding to improve the N use efficiency of this cereal at the plot level: slow-germinating and long-duration varieties give high yields at low N doses, and among 20 N-responsive traits, six are related to N use efficiency. Other scientific communications showed that the adjustment of the dose, date or tillage during N fertilisation, the choice of the N source according to regional specificities (e.g. natural or synthetic urease or nitrification inhibitors, coated urea, combined with irrigation, biochar enriched with nutrients and residue-based fertilisers) or a change in crop rotation influences ammonia emissions and improves N use efficiency and yields. They concluded that these factors and strategies need to be considered when designing public policies that aim to reduce N waste. There has also been significant progress in measuring ammonium and nitrous oxide fluxes worldwide, but there is still a need to extend the area covered by these measurement systems, to measure the different forms of N simultaneously on a frequent basis so as to increase our understanding of N losses and to consider indirect nitrous oxide emissions. Finally, N use efficiency, cycling and functionality in pasture and grassland systems is challenged by climate change and intensification, but is supported by improved fertiliser decision support, increased N fixation, mixed grassland, recycling of human excreta and treatments to mitigate N losses.

At the **livestock or mixed systems** scale, Aimable Uwizeye highlighted that the growth of the livestock sector, which has been especially concentrated in regions with low production costs, has seriously altered the N cycle. Consequently, there is significant room for improvement of N use efficiency at all stages of the life cycle of animal products, both to reduce environmental pressure and to increase farmers' income. The communications of this regular session emphasised that predictive feeding as well as new housing strategies and technologies can potentially increase N use efficiency and decrease losses at the farm level. Regarding manure management, slurry acidification is one of the most widely studied practices that demonstrates its ability to reduce N emissions (ammonia and nitrates but not nitrous oxide) when applying animal excreta to agricultural land. However, the achievement of N loss reduction targets for some regions and countries will not be possible at the national and regional scales without recourse to a reduction in livestock numbers. Finally, modelling is useful to assist farmers in decision making, to assess systems and to support public policy making. Combining measurement approaches and modelling in decision support tools helps even more to identify climate change mitigation measures at the farm level.

At the **agro-food system** scale, Gilles Billen described how an agroecological bifurcation would have a stronger abatement impact than a “Farm to Fork” strategy implementation (or other current measures proposed by national and transnational public institutions) and has the potential to halve N waste. As stated by further communications, comprehensive and integrated analyses have made impressive progress in recent years, both in terms of new methods and extensive data sets with components that were previously poorly documented (e.g. GHG emissions, air pollution and energy flows). The ambitious target of halving N losses has led to an even wider range of non-prescriptive scenarios of possible solutions.

At the **landscape scale**, Estela Romero showed that human decisions on nutrient and water management, as well as river and estuary modifications, are clear drivers of N transport from land to sea. Jill Baron, using the example of Rocky Mountain National Park in the United States, supported the need to change legislation and subsidy rules to significantly reduce N pollution, since voluntary implementation of best management practices by farmers is not enough. The rest of the communications concluded that excess N inputs to agricultural systems are evident in contrast to natural ecosystems in most countries. However, there is still a N input deficit in some of the world’s countries. Measuring and monitoring reactive N is therefore central to understanding these excesses. Excessive N inputs pollute surface and groundwater as well as coastal areas. Therefore, it seems important to integrate water quality and aquatic ecosystems into global and regional assessments of N flows, and specifically to recycle reactive N. Taking into account variations in soil organic N stocks in budgetary approaches is also important, given that it can be a source of decorrelations between N use efficiency and losses.

The two **roundtables** of private and public actors in the fertiliser and feed sectors provided an opportunity to hear their views on the scientific research conducted and presented at the workshop and how it is being used, the evolution of the products they operate and finally their vision of the future and the role they intend to play. The **fertiliser industry** highlighted the influence of the concept of N use efficiency on nutrient and environmental policies and conveyed a vision of a carbon-neutral society in the future using hydrogen as an energy carrier and using ammonia (converted from hydrogen) for energy storage and transport. For its part, the **feed industry and policy makers** highlighted the progress made in the last few decades in animal feeding to increase efficiency and reduce N excretion. To advance even further, it is important to increase the use of local feed resources and avoid raw materials with a high environmental impact.

The **special sessions** deepened the interest of remote sensing tools to improve N use efficiency at the plot level as well as to exchange on public policies and their costs and benefits to reduce N losses. Urs Schmidhalter opened the special session on **remote sensing and precision agriculture** by presenting the state of the art of the potential of this tool to optimize N fertilization, i.e. increase N use efficiency and thus reduce N waste. Following this path, further communications underlined that it is nevertheless necessary to extend the use of these sensors within farms and to continue research to consolidate the understanding of the spatial and temporal dynamics of N in plants and soils using data from these sensors. As for **public policies** designed to reduce N pollution, they generally aim to repair the negative impacts of other public policies and differ from one country to another, i.e. depending on the socio-economic context. Recent public policies, faced with a growing demand for efficiency, voluntarily integrate participatory approaches. The success of these approaches is nevertheless mixed (depending on the level of demand). Furthermore, these public policies should promote strategies involving stakeholders in the implementation of a N **circular economy**, especially concerning water streams. In addition, they should not conflict with climate policies. **Cost–benefit** analyses of these policies support decision-making processes at all scales. A key method for these analyses is benefit transfer, but the uncertainties are considerable and not well understood when the scales are large and the time horizons long.

These rich **convergent or complementary conclusions** obtained at **different scales** and with **different methodologies** reinforce the benefit of integrating **diverse spatial and system scales** within the same meeting sessions, as well as dedicating several special sessions to **social science** approaches. We now know that a wide range of measures can reduce N losses, that halving these losses requires both technical and structural changes and that the benefits outweigh the costs. Despite this key knowledge, implementation is not easy and requires complex public and private actions and interactions and in some cases raises conflicts of interests. The policy and social dimensions have to be reinforced to reduce N waste as soon as possible and should be more present in the N workshop in the future. The perspectives of the research presented during this workshop as well as the high level of uncertainty surrounding the political and environmental context over the short term (e.g. geopolitical instability, global peak oil, climate change), announce a XXIInd edition of the N workshop already rich in content and debate on strategies to halve N wastes by 2030.

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