International Research Symposium on Agricultural Greenhouse Gas Mitigation

From Research to Implementation

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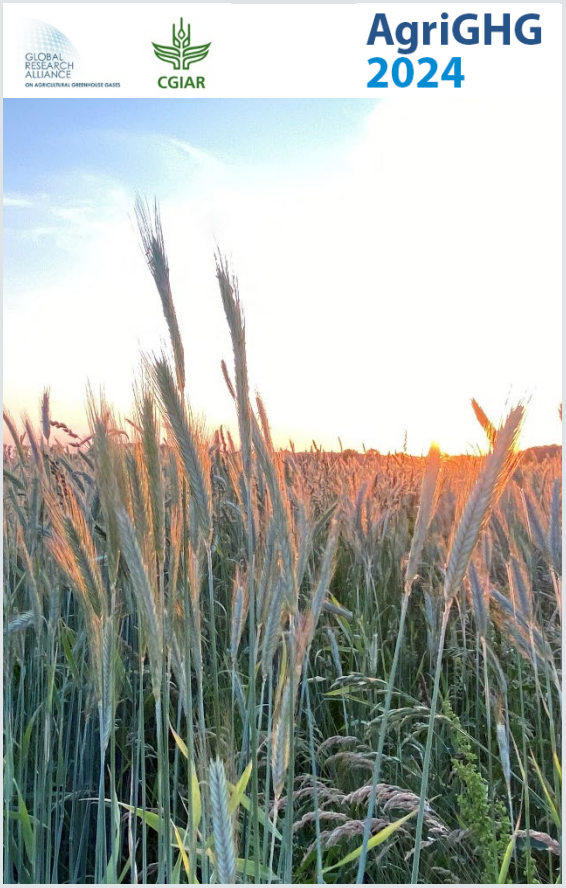
Book of Abstracts



Claudia Heidecke, Harry Clark, Louis Verchot, Til Feike, Nina Grassnick, Andy Reisinger, Claudia Ringler, Tania Runge, Wei Zhang (Eds.)

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Preface

Total net GHG emissions from Agriculture, Forestry and Other Land Use (AFOLU) averaged around 12.0 GtCO2eq per year during 2007–2016. Approximately 23% of total anthropogenic greenhouse gas emissions derive from AFOLU, while the global food system contributes nearly one third of global greenhouse gas emissions (IPCC 2023). At the same time as being a major emitter, the global food system is called upon to produce approximately 40% more and more diverse foods during 2020 to 2050 to improve the food security, diets and human health of a larger, more urbanized, and better off (but less equal) larger population. With two thirds or more of populations in low- and middle-income countries (LMICs) unable to afford and access healthy diets, there is a particular need to increase production of animal-source foods, fruits and vegetables. At the same time, the productivity of agri-food systems is increasingly impacted by climate change, contributing to a negative feedback loop of climate change induced production expansions that, in turn, fuel climate change.

Since the Paris Agreement in 2015 all countries are “pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels”, while taking steps to “increase the ability to adapt (…), foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production” (PA, 2015). Effectively, measures to limit climate change, such as through biofuel development, or solar-powered electricity development on agricultural lands have already negatively affected food production; and have arguably slowed fossil-fueled agricultural mechanization, investments in livestock systems, and agrochemical access in LMICs. Impacts from unmitigated climate change, on the other hand, are wreaking havoc on production systems, affecting smallholder producers the most, with dramatic increases in inequities in access to food and global increases in undernutrition and food insecurity.

Thus, it is becoming more and more crucial to develop and implement effective, locally suitable and sustainable solutions for mitigating emissions from food systems and for actively supporting management of carbon sinks, with differentiated, but highly targeted approaches for different regions of the world. Implementing measures at scale requires not only major increases in financial investments but also embracing a just climate transition where the voices of those who have most to lose from climate inaction are heard, and resources are targeted to the most marginalized food producers and consumers, including women farmers.

While localizing solutions is important, improved information flows across geographies together with an enabling environment supporting innovations can spur learnings from mitigation successes and failures, help modify and contextualize solutions that have been developed for other locations, circumstances and conditions, identify new approaches and ideas, support capacity sharing and cooperation with LMICs, and can ultimately increase and improve the quality of and equity in mitigation action.

The aim of this “International Research Symposium on Agricultural Greenhouse Gas Mitigation - from Research to Implementation” is to facilitate international exchange, to foster more and better implementation of climate mitigation measures in the agri-food systems sector, to give new impetus to, grow existing and develop emerging mitigation networks and their activities and to identify new opportunities and ideas for research cooperation at European and international level.

This book of abstracts provides examples of research activities being conducted in different parts of the world. Options for climate change mitigation measures, monitoring, reporting and validation, effective and rapid implementation, the identification of win-win-solutions, implications for global agricultural trade, and a just climate transition are key topics covered in support for ambitious and comprehensive mitigation action. In addition, options and barriers for implementation and--critically--how to leverage the finance needed to successfully overcome the challenges posed by climate change are discussed.

Specific topics addressed in detail include:

- Innovations and technology options for nitrous oxide emissions reductions
- Innovations and technology options for methane reduction through feed and manure management
- Potentials for SOC and peatland rewetting
- Meeting 2050 targets and supporting net zero
- Evaluating costs of mitigation and options for implementation
- National policy analysis for climate action
- Innovations and technology options for methane reduction in rice production
- Just transitions towards low-emission and resilient agri-food systems
- GHG modelling approaches and tools
- Integrated assessment of food systems including the role of carbon markets
- Low emission development pathways for the livestock sector
- Novel approaches for MRV and potential for remote sensing and AI modelling
- Agroecology, Agroforestry, Ecosystem services
- Farm level implementation and managing synergies and trade-offs of mitigation

This symposium and the book of abstracts contributes to the Sharm el-Sheikh Joint Work on implementation of climate action on agriculture and food security (SJWA) of the UNFCCC. The program aims to enhance research and development on issues related to agriculture and food security and to share scientific, technological and other information, knowledge (including local and Indigenous knowledge), experience, innovations and best practices.

Low-emission development pathways implemented in the light of different regional conditions and considering different voices and vulnerabilities are key for food security, a sustainable future and livable planet. In this context, we sincerely hope that this symposium and the book of abstracts will contribute to the aims of the SJWA and enhance progress by fostering global knowledge exchange, sharing experiences and forging new collaborations and friendships

The Editors

Claudia Heidecke, Harry Clark, Louis Verchot, Til Feike, Nina Grassnick, Andy Reisinger, Claudia Ringler, Tania Runge, Wei Zhang

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Policy progress towards a low emitting AFOLU sector: Insights from OECD work

GUILLAUME GRUERE

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Governments in OECD countries and other countries have committed to take action to reduce greenhouse gas (GHG) emissions in agriculture, forestry, and other land use (AFOLU), through ministerial declarations, pledges, and targets. There is a significant potential for policies to significantly contribute to GHG mitigation, either through emission reduction or carbon sequestration. The presentation reviews findings from recent OECD work to measure policy progress towards these commitments and potential. This includes an upcoming international inventory of direct and indirect policy actions in AFOLU, recent work on the GHG mitigating effects of policies and analyses of agricultural policies that may go in the opposite direction. The combined evidence suggests that, while progress can be seen, policies in place in the AFOLU sector are not the most effective at mitigating emissions, for varied reasons. It also identifies areas for additional research. Lastly, the presentation highlights the diversity of national policy approaches, responding to different contexts, but that may induce spillover market-related effects in terms of competitiveness and carbon leakage in the future.

Food matters: Dietary shifts increase the feasibility of 1.5 °C pathways

FLORIAN HUMPENÖDER

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A transition to healthy diets like the EAT-Lancet Planetary Health Diet could considerably reduce GHG emissions. However, the specific contributions of dietary shifts for the feasibility of 1.5°C pathways remain unclear. Here, we use the open-source Integrated Assessment Modeling (IAM) framework REMIND-MAgPIE to compare 1.5°C pathways with and without dietary shifts. We find that a flexitarian diet increases the feasibility of the Paris Agreement climate goals in different ways: The reduction of GHG emissions related to dietary shifts, especially methane from ruminant enteric fermentation, increases the 1.5°C-compatible carbon budget. Therefore, dietary shifts allow to achieve the same climate outcome with less carbon dioxide removal (CDR) and less stringent CO2 emission reductions in the energy system, which reduces pressure on GHG prices, energy prices and food expenditures.

The potential of new technologies to reduce greenhouse gas emissions from agriculture

SINEAD LEAHY

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Co-authored presentation by all research group chairs of the Global Research Alliance on Agriculture Greenhouse Gases:

GRA Livestock Co-chairs: Leahy SC. Boland T, Dewhurst R

GRA Paddy rice Co-chairs: Yasuhito Shirato, Omar Ndaw Faye, Alvaro Roel

GRA Cropping Co-chairs: Hero Gollany, Rosa Mosquera Losada, Ladislau Martin

GRA Integrative Co-chairs: Jean-Francois Soussana, Pamela Joosse, Nadia Bouhfas

Agriculture is the largest contributor to both global anthropogenic methane and nitrous oxide emissions and agricultural emissions are rising. Increases are due to a growing human population and increasing demand for animal protein as incomes rise, but with significant variations in demands and trends between regions and countries. While on-going improvements in production efficiencies are essential, new technologies that directly target the reduction of agricultural greenhouse gas emissions are urgently required to bend the emissions curve while production grows. This presentation will provide an overview of some of the novel approaches emerging. Accelerating the development and deployment of these new technologies could significantly increase the ability of the agricultural sector to reduce its emissions globally and achieve mitigation at scale.

Resilient and low emission development pathways in low-income countries: food security, greenhouse gas mitigation and adaptation

GEORGE WAMUKOYA

Team leader of AGNES and lead negotiator on agriculture for G77 (on mitigation pathways for Africa), Kenya

Climate change poses a significant threat to agriculture and food security of most of the low-income countries commonly referred to as least developed countries (LDCs). This has implications on the national economies and livelihoods and incomes of the Climate change affects agriculture through changes in temperature, precipitation patterns, extreme weather events, and shifts in pest and disease dynamics. These changes have profound implications for food security, rural livelihoods especially of small-scale farmers, pastoralists and fishers, and environmental sustainability. To mitigate these challenges, sustainable land and water management practices, adoption of climate-resilient agricultural practices, and technological innovations are essential to enhance the resilience of agricultural systems to climate change. In addition, according to the national communications, the main sources of emissions in most LDCs is agriculture, forestry and other land use (AFOLU) sectors. However, LDCs and Small Island Developing States (SIDS) are not obligated to mitigate GHG emissions, business-as-usual is not an option. This calls for a paradigm shift and collaborative efforts among governments, farmers, researchers, and policymakers to implement adaptation actions that have mitigation co-benefits. By addressing the challenges posed by climate change and adopting adaptive strategies, global agriculture in these countries will be transformed to become more resilient and sustainable in the face of changing climatic conditions. For this transformation to happen, it will require developed countries to provide means of implementation (finance, technology development and transfer and capacity building.

Opportunities and challenges for (voluntary) carbon markets and payment incentives

EVA (LINI) WOLLENBERG

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Carbon markets pose an opportunity for huge impact on mitigation in agriculture, yet also face challenges that may constrain use of the instrument in the future. This presentation provides an overview of the market, the extent of agriculture in the market and some issues and trends. The carbon market is one of several economic incentives in agriculture for mitigation, which include enhanced agricultural productivity, financial transfers, carbon market and carbon taxes and pricing. Carbon markets are trading systems in which carbon credits are sold and bought. Companies purchase C credits from entities that remove or reduce GHG emissions to make compensatory ("offset") or impact claims. The two main types of markets are the voluntary market, driven by the private sector and valued at USD 2 billion at its peak in 2021, and the compliance market, regulated by governments and valued at USD 899 billion at its peak. The international carbon market has been guided by UNFCCC policy, which presently is focused on Article 6.4, which creates a market mechanism that may overlap, compete or integrate with the VCM.

A review of current global emissions trading systems (ETS), government crediting mechanisms and the voluntary market shows that agriculture is relatively poorly represented compared to other sectors. There are no agricultural projects or credits issued yet under ETS schemes, only eight countries with 4,754 projects and 653 thousand credits under agricultural projects, and 8,929 projects and 1.9 billion credits under agriculture in the voluntary carbon market (VCM). The VCM is the locus of most agricultural projects, even though they comprise only 10% of VCM projects and 1% of VCM credits issued so far. Methane digester projects are the largest source of VCM agricultural credits.

Agricultural actors in the VCM includes diverse groups often playing multiple roles. Examples of current carbon programs for farmers include Soil Capital, CIBO, and TruTerra and highlight the increasing interest in soil carbon in the market. Farmers view the carbon market as providing low compensation, requiring paperwork, lacking predictability and risking greenwashing. Integrity breaches have been a challenge throughout the history of the VCM and more actors are being held accountable in recent years. Integrity initiatives such as the Integrity Council for the Voluntary Carbon Market (ICVCM) are also certifying standards. Other trends in the market include the increasing role of carbon pricing in middle-income countries including Brazil, India, Chile, Colombia, and Türkiye; New Zealand pushing their plan to price agricultural emissions in 2025 to 2030; the initiation of the EU Carbon Border Adjustment Mechanism, requiring importers of specified products to report embedded emissions; and governments increasingly using multiple carbon pricing instruments in parallel to expand coverage or price levels. The German government's CompensAction Initiative is an example of seeking to use multiple mechanisms to fairly compensate smallholder farmers for their ecosystem services.

A forthcoming FAO report on Agrifood Systems in the Voluntary Carbon Market: Status and Prospects will be available in early 2025 with more analysis and detail. The future of the VCM remains uncertain, depending on the allowance of offsets, development of the Article 6 mechanism, and effectiveness of other C pricing mechanisms. This leaves open the question of what are the best mechanisms to incentivize significant mitigation while delivering agricultural benefits and enable significant compensation to farmers, especially smallholder farmers in LMICs.

2 Talks

Abstracts in alphabetical order

An Assessment of Food Loss Among Arable Crop Farmers in Nigeria

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Carbon dioxide released into the atmosphere due to the loss or waste of food crops is a considerable contributor to the emission of greenhouse gases (GHGs), which in turn exacerbates the problem of climate change and the ongoing food crisis. It is widely recognized that food waste and loss are major concerns. If these issues were considered as a country, it would rank as the third-largest emitter of greenhouse gases globally. There is broad consensus that addressing this problem would help significantly lower GHG emissions and enhance the sustainability of food systems. Most studies on this topic have been conducted in the Global North. However, limited data is available for the Global South, where significant arable crop losses occur during production and distribution. Less than 35% of annual global studies on food loss have focused on these stages. In this study, food loss is described as any food originally planned or cultivated for human consumption, but omitted (irrespective of the alternative purpose) between the production and distribution stages. This omission has partially contributed to the current food crisis in the developing countries. In Nigeria, food loss has intensified, thereby increasing the problem of limited access to food. In terms of food security, the country is ranked 25th among 28 African countries. Among the studies conducted globally on food loss between 2016 and 2022, Nigeria was classified among the top ten countries with the most case studies. Paradoxically, millions of people suffer from hunger and malnutrition in the same country in which food is lost. Given this context and global interest in finding a sustainable solution to the problem, understanding the underlying reasons for continuing food loss in this region is pertinent. Although a wealth of literature is available on this subject, most studies employ quantitative research methods. Regrettably, with such an approach, the role of food valuation practices among key actors such as arable crop farmers has received little attention. This study attempts to fill this knowledge gap by examining food loss through the lens of valuation, suggesting that individuals and groups have different values that impact their economic activities. Primary data were collected from arable crop farmers in Nigeria using qualitative research approaches such as observation, focus group discussions (FGDs), and participant interviews. Ultimately, this study explores the outcomes of valuation practices, specifically actors' actions, practices, and perceptions, that influence food loss. The insights gained from this study are expected to foster the design of sustainable impact-driven food loss reduction policies and interventions in Nigeria.

Keywords: food systems, food loss, food waste, climate change, food security

Peatland emission reduction and gaps for advancement to Tier 3 inventory in Indonesia

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Tropical peatlands are critical carbon reservoirs, but their drainage and subsequent use lead to significant greenhouse gas (GHG) emissions, especially carbon dioxide (CO_2), due to peat decomposition and fires. This review examines advancements in inventory methodologies and identifies critical gaps necessary for transitioning to a Tier 3 approach. While expanding oil palm cultivation on low biomass carbon stock lands may be carbon neutral or even carbon positive, the situation on peatlands is different, as CO_2 emissions from decomposition continue to rise with increasing drained areas. Raising the water table, particularly through canal block construction, is a key strategy for reducing these emissions. Significant progress has been made in developing mathematical relationships between water table levels and CO_2 emissions, as well as between plant age and CO_2 emissions. However, gaps in activity data hinder the full application of these findings. The current monitoring scheme of water tables at "obedient points" is inadequate, underscoring the need for multi-location, multi-year research to generate reliable activity data, such as weighted average water tables influenced by canal blocks. Additionally, there are substantial gaps in the inventory of peat fire emissions, particularly in estimating the volume of burned scars, which necessitates the use of cost-effective remote sensing technologies. Moreover, while models are being developed to simulate water table dynamics with canal blocking, a lack of calibration data remains a challenge. Addressing these gaps is crucial for advancing inventory methodologies and enhancing emission reduction strategies in Indonesia and other tropical peatland regions.

Keywords: activity data, burn scar, canal block, low carbon stock land, peat decomposition emission

Mitigation practices for low-carbon livestock in sub-Saharan Africa: A Living Laboratory approach

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Climate change mitigation and adaptation is a global challenge. For livestock production in Sub-Saharan Africa (SSA), efforts have been directed towards sustainable solutions for the sector. The objectives of this study were (i) to identify facilities where different mitigation practices have been evaluated and implemented in SSA, and (ii) to create a living laboratory where stakeholders within the livestock value chain collectively evaluate enteric methane (CH_4) mitigation practices with the shared goal of transforming practices to be more environmentally responsible and climate resilient.

A research network was created through a project called "Methods to evaluate low-carbon livestock in sub-Saharan Africa" (MECLAN). MECLAN identified institutions where greenhouse gases (GHG) mitigation practices were evaluated and quantified. Two approaches were explored (i) literature review through bibliography search, and (ii) existing research network of SSA countries and France focusing on GHG emission in SSA. A web application was developed as a tool to aggregate information on African institutions (shown on an interactive map); climatic conditions using the Koöppen classification; facilities, equipment and methodologies available for GHG quantification; species and breeds of experimental animals; diets and feedstuffs (details on availability and chemical composition), animal performance indices, published articles on GHG emissions from the institution; and contact details for researchers. A database will be created to aggregate all collected information via this web application and literature review. This data will be subjected to statistical analyses to assess the most prominent mitigation practices in SSA. Other identified stakeholders in research and development from the database will be incorporated into the existing research network for mitigation practices sustainability and cleaner farm environment policies. A transdisciplinary living laboratory approach involving farmers, existing research networks and other non-governmental and governmental organizations will be used to co-design, monitor, and evaluate the impact of the adoption of mitigation practices on productivity and livelihoods.

The web application is currently undergoing alpha testing and will be deployed for use after the beta testing. Twelve organizations are involved in MECLAN including Food and Agriculture Organization (FAO), Italy, Institut national de recherche pour l'agriculture, l'alimentation et l'environnement (INRAE), France; Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France; International Livestock Resaerch Iinstitute (ILRI), Kenya; University of Pretoria, South Africa; Institute of Rural Economy, Mali; Institute of Environment and Agricultural Research (INERA), Burkina Faso; Université d'Abomey-Calavi (UAC), Benin ; Institut Sénégalais de Recherches Agricoles (ISRA), Sénegal, Université d'Antananarivo, Madagascar; Institut de Recherche en Elevage pour le Développement, Tchad and National Center for Applied Research in Rural Development (FOFIFA), Madagascar. This was extended to sixteen (16) with the addition of other identified organizations (Obafemi Awolowo University, Nigeria; University of Parakou Benin; Natural Resources Institute Finland (LUKE); and International fund for Agriculture development (IFAD) Italy) in living lab system. The results of this project will be used to develop specific enteric methane prediction models for SSA and to support policies for sustainable livestock production and climate resilience in SSA.

Keywords: Sub-Saharan Africa, web application, mitigation practices, living laboratory, enteric methane

Assessing and developing methane emission prediction models for cattle: A focus on India

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India is home to over 525 million ruminants, which are major contributors to global warming via enteric methane (Ent_{CH4}) emissions. Various strategies exist to reduce Ent_{CH4} emissions but accurate emission estimates are needed to predict the potential of each mitigation strategy. Measuring Ent_{CH4} emissions is expensive and unrealistic on a large scale, so there is an urgent need for accurate Ent_{CH4} prediction models. The present study evaluated the accuracy of various published models and developed a simplified model for predicting Ent_{CH4} emissions from cattle across the Indian subcontinent. Six Ent_{CH4} prediction models based on either dry matter intake (DMI) or gross energy intake (GEI) were identified as applicable to India. DMI- and GEI-based models were taken from IPCC (2019) ($IPCC_{DMI}$ and $IPCC_{GEI}$), Ribeiro et al. (2020) (Rib_{DMI} and Rib_{GEI}), and Patra (2017) (Pat_{DMI} and Pat_{GEI}). These were evaluated using two independent literature databases containing information on 386 lactating cattle from 15 studies and 122 non-lactating cattle from 13 studies under different management practices across 13 Indian states. In addition, both datasets were combined to develop an empirical Ent_{CH4} prediction model. Data were divided with a 70:30 ratio for model training and testing, respectively. The relative prediction error (RPE) and concordance correlation coefficient (CCC) were used to evaluate model accuracy. A model's prediction was considered acceptable when RPE < 20%. Of the six models evaluated, the most accurate models for lactating cows were Rib_{DMI} (RPE = 18.6%, CCC = 0.695) and Pat_{DMI} (RPE = 18.4, CCC = 0.690), while the other models yielded estimates with RPE > 20%. None of the six models predicted Ent_{CH4} for non-lactating cattle with RPE < 20% or CCC > 0.20. The linear model developed (Ent_{CH4} (g/day/cattle) = 2.82 + 17.53 × DMI (kg/day), R^2 = 0.78) predicted Ent_{CH4} with a lower RPE (9.9%) than the six models evaluated. In conclusion, Rib_{DMI} and Pat_{DMI} are the best performing models for Ent_{CH4} in India, and the proposed simplified model has good predictive accuracy, until new nationwide models based on larger data sets have been developed.

Keywords: enteric methane emissions, model accuracy, mitigation potential

Environmental and Food Security Implications of Livestock Abortions and Calf Mortality: A Case Study in Kenya and Tanzania

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In many lower-middle-income countries, particularly in Africa, addressing protein deficiency amid rapidly growing populations presents a critical challenge. This study examines the environmental and food security implications of livestock abortions and calf mortality in Kenya and Tanzania, highlighting how enhancing livestock health can significantly improve productivity and sustainability. The research targets dairy systems in Tanzania and beef systems in Kenya, utilizing data from prior studies to estimate the greenhouse gas (GHG) emissions per unit of animal product, referred to as emission intensity (EI). In Tanzania, the analysis focuses on the impact of livestock abortions on GHG emissions across different cattle and goat breeds in dairy systems. Meanwhile, in Kenya, the study shifts to beef systems, assessing how calf mortality influences emissions through both lifetime methane production and carcass output. A life cycle assessment using the Global Livestock Environmental Assessment Model-interactive (GLEAM-i) aids in examining GHG sources and potential trade-offs. The study quantifies milk and carcass losses due to abortions and calf mortality, scaling these figures to national levels. The findings reveal that in Tanzania, abortions can increase milk EI by up to 18%, depending on the breed. In Kenya, varying rates of calf mortality result in emissions ranging from 25.9 to 27.6 kg CO_2 equivalent per kg of carcass weight. Notably, reducing calf mortality to 8%, 4%, and 0% could correspondingly reduce EI by 3.2%, 4.6%, and 5.9%. These results underscore the substantial impact that improving animal health can have on both reducing GHG emissions and enhancing the availability of animal protein. Specifically, effectively addressing livestock health issues in Tanzania could potentially satisfy the protein requirements of approximately 1.3 million people. Similarly, in Kenya, reducing calf mortality could meet the dietary protein needs of about 4.5 million people. This research highlights the dual benefits of targeted livestock health interventions: lowering GHG emissions and boosting food security. Such efforts are crucial for sustainable livestock production in developing regions, underscoring the need for a systems perspective to comprehensively assess the broader environmental impacts of livestock health issues.

Keywords: abortion, calf mortality, GHG, methane, emission intensity, animal protein, food security, animal health

Climate-smart legume grass species can reduce greenhouse gas emissions and net SOC

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Improving forage productivity with lower greenhouse gas (GHG) emissions from limited grassland has been a hotspot of interest in global agricultural production. In this study, we analyzed the effects of grasses (tall fescue, smooth bromegrass), legume (alfalfa), and alfalfa-grass (alfalfa + smooth bromegrass and alfalfa + tall fescue) mixtures on GHG emissions, net global warming potential (Net GWP), yield-based greenhouse gas intensity (GHGI), soil chemical properties and forage productivity in cultivated grassland in northwest China during 2020–2021. Our results demonstrated that alfalfa-grass mixtures significantly improved forage productivity. The highest total dry matter yield (DMY) during 2020 and 2021 was obtained from alfalfa-tall fescue (11,311 and 13,338 kg ha^{-1}) and alfalfa-smooth bromegrass mixtures (10,781 and 12,467 kg ha^{-1}). The annual cumulative GHG emissions from mixtures were lower than alfalfa monoculture. Alfalfa-grass mixtures significantly reduced GHGI compared with the grass or alfalfa monocultures. Furthermore, results indicated that grass, alfalfa and alfalfa-grass mixtures differentially affected soil chemical properties. Lower soil pH and C/N ratio were recorded in alfalfa monoculture. Alfalfa and mixtures increased soil organic carbon (SOC) and soil total nitrogen (STN) contents. Importantly, alfalfa-grass mixtures are necessary for improving forage productivity and mitigating the GHG emissions in this region. In conclusion, the alfalfa-tall fescue mixture lowered net GWP and GHGI in cultivated grassland while maintaining high forage productivity. These advanced agricultural practices could contribute to the development of climate-sustainable grassland production in China.

Keywords: soil organic carbon, legume grasses, greenhouse gas emissions, soil fertility, regenerative agriculture

Remodelling soil carbon stocks to meet carbon trading requirements

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Carbon farming-based trading schemes (CFTS) have been proposed to incentivize contributions of the agricultural sector to climate change mitigation, and soil organic carbon (SOC) sequestration is recognized as the principal measure. Several models have been developed to estimate the biogeochemical processes involved in the SOC cycle in agroecosystems. However, the most frequently applied models rely on multiple compartments as conceptual carbon entities, making their state variables not fully verifiable by standard SOC stock determinations. Thus, they are often prone to overparameterization and overfitting, leading to SOC forecasts with inflated uncertainties, hindering their use in measuring, monitoring, reporting and verification (MMRV) protocols. Few studies have assessed the efficacy of current SOC models for MMRV protocols, while rarely any of those models' design has explicitly addressed the CFTS's requirements. We aim to contribute to fulfill that gap by offering a new SOC dynamic model holding the same fundamental principles of most applied SOC multicompartment models and can match their estimates with a single measurable SOC compartment. We improved the adherence to empirical data by making model state variables limited to those of interest for CFTS, i.e., SOC stocks and carbon decomposability. Single compartment decomposability can be estimated from longitudinal SOC stocks and carbon input data, so that both state variables are comparable to empirical measurements available for calibration, evaluation and model-data fusion procedures. The novel model prevents overparameterization and overfitting via a new mathematical formulation with reduced number of decomposition parameters and can accurately reproduce multicompartmental models' SOC forecasts with a single compartment.

Keywords: soil organic carbon, dynamic modelling, carbon turnover, ordinary differential equations, carbon quality models

Opportunities and Limitations of Farm-Level-GHG-Accounting Tools: Experience from practice

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Driven by growing awareness of the environmental pressure emanating from food systems, ever more private stakeholders and administrative bodies are signing up for science-based targets. In this context, a growing demand for farm level greenhouse gas (GHG) accounting tools can be noticed, allowing assessments of specific emission profiles as well as ex-ante and ex-post estimates of GHG reduction potentials. A corresponding MRV (Measurement, Reporting and Verification) system is not only necessary for quantifying mitigation effects and guiding management and policy decisions but also for compensating actors and particularly farmers for financial and other expenditures. So far, farm level GHG accounting tools have been mainly used in scientific modelling exercises and the respective insights are of rather theoretical nature. Here we explore opportunities and limitations of farm level GHG accounting tools based on a global survey covering the practical application of 23 tools used in 30 projects worldwide.

Notably, most of the projects participating in the survey are based in industrialized countries and, although practice-oriented, are linked to scientific and/or government programs. GHG accounting tools are typically used by experienced experts with a professional background in natural sciences. Awareness raising and consultancy are the main purposes with barely any “hard” application, i.e.., for determination of (financial) rewards or eligibility for label programs.

The typical tool is of medium complexity and applies system boundaries from cradle to farm gate. Carbon sequestration in soils and biomass is only considered in about half of the tools, with diverse methodological approaches. Data quality, leakage and uncertainty is only assessed in a few cases. Furthermore, the survey results suggest that certain system interactions and particularly consequential effects due to the competitive use of land and biomass (e.g., feed-food competition) are considered relevant by many participants but are addressed differently, if at all in the individual projects. Yet another challenging feature is the emission allocation to individual activities and/or products.

On average, theoretically achievable GHG reduction potentials on commercial farms are estimated to be in the order of 22%. However, practically realizable and actually achieved reduction potentials are considerably lower at around 14%.

In conclusion, we find that individual farm greenhouse gas accounting is highly complex and time-consuming and should be primarily used in a farm advisory context with professional support. A fair and solution-oriented interpretation of the results, taking into account local site conditions and consequential effects in the entire food system, requires great experience. Methodological limitations and lack of transparency harbor the risk of misinterpretation, particularly with regard to the efficient use of limited land and biomass resources on a global level. Accordingly, different indicators (set of key figures and reporting units) and different benchmark approaches should be considered in a comprehensive assessment. Furthermore, the limited technical reduction potentials and the challenges regarding their quantification, designation and fair compensation show the limits of the individual farm approach to agricultural climate mitigation and, at the same time, point to the need for structural adjustments at a higher level.

Keywords: MRV, tools, accounting, practice, greenhouse gas

Farmers' perception of the efficacy of adaptation and mitigation strategies

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The global agricultural systems face significant challenges due to climate change, which require effective adaptation strategies. This study explores Gambian smallholder farmers' perception regarding the effectiveness and impact of adaptation and mitigation strategies within the context of farming system changes and land management practices. A survey with smallholder farmers in the Gambia was conducted to assess their perceptions of the efficacy of climate risk adaptation and mitigation strategies. The effectiveness of these strategies was evaluated by asking farmers to rate them on a Likert scale from 1 to 5 with 1 indicating totally ineffective and 5 indicating highly effective. To quantify farmers' perceptions, a perception index was developed. This index was calculated by assigning numerical values to the Likert scale response provided by farmers for each strategy. Through a thorough analysis, the research sheds light on the differing levels of efficacy and understanding of different adaptation and mitigation measures among farmers in the region.

The finding revealed that smallholder farmers consider both adaptation and mitigation strategies as crucial for alleviating the impact of climate change on agricultural productivity. Adaptation strategies such as changing crops to livestock, using inorganic fertilizers, pesticide application, irrigation, praying, use of insurance, wage migration, assistance from government/non-governmental organizations, and mitigation strategies such as changing seed quality and stop cutting trees, are perceived as effective strategies. These strategies are perceived as urgent solutions to adapt and mitigate the impact of climate change on agricultural productivity. Furthermore, the study also examines the economic, social, and environmental impact of the adaptation and mitigation measures by assessing farmers' expectations with the implementation of different strategies, thus providing a holistic understanding of the outcome of implementing various strategies in agricultural practices. Synthesizing these results, a perception index is established at 0.66. This index signifies a moderate level of perceived efficacy of climate risk adaptation and mitigation strategies among smallholder farmers in the Gambia. This suggests that farmers have a good understanding of some strategies but there is still room for improvement in enhancing the awareness and knowledge of other adaptation and mitigation strategies.

The result highlights the significance of comprehending farmers' perceptions to enhance the adoption and effective climate risk adaptation and mitigation strategies in evolving farming and land management paradigms. The study highlights the importance of integrating farmers' perceptions into climate adaptation and mitigation strategies to better meet the needs of local agricultural communities. By acknowledging and addressing farmers' realities, policymakers can better tailor interventions for improved effectiveness and sustainability in the face of global climate change. This research offers valuable insights into the efficacy of adaptation and mitigation strategies in The Gambia, emphasizing the crucial role of farmer engagement in enhancing adaptation efforts in agriculture.

Keywords: climate risk, perception index, efficacy, adaptation, mitigation

Carbon-scaled N_2O emissions for a better assessment of impacts of land use systems

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Agricultural expansion causes significant land use change concerns (hotspots) in the Dry Chaco region of Argentina. In this region, the traditional rotation of soybean and maize in the summer and wheat or fallow in the winter (as the major drivers of the country's economy) have pushed the agricultural frontier over native forest. However, the post-impact of this land use change on nitrous oxide (N_2O) emissions and carbon (C) budgets remains unknown.

This study aimed to compare the impacts of the main land use systems of this region on N_2O emissions related to their C inputs and C budgets by comparing them with those of a native forest at two sites. At Site 1, the land use systems were soybean-fallow-soybean and maize-fallow-maize sequences, whereas at Site 2, it was a soybean-wheat sequence. Measurements of soil N_2O and carbon dioxide (CO_2) fluxes were carried out monthly using the static chamber method. The C budgets of each system were determined for the annual crop-fallow ot crop-crop (depending on the site) cycle by the difference between the C inputs (from annual aboveground biomass (ABG), belowground biomass (BG), and rhizodeposition) and C outputs (defined as cumulative annual CO_2-C emissions).

In Site 1, the native forest showed 168 and 50% more cumulative N_2O emissions than maize-fallow and soybean-fallow, respectively, whereas in Site 2, it had less than half of the cumulative N_2O emissions of the soybean-wheat sequence. However, when cumulative N_2O emissions were relativized to their C inputs, native forests emitted less and the same amount of N_2O per tonne of C entered each system than soybean-fallow/wheat and maize-fallow, respectively. The C budgets (± standard error) in Site 1 were 6.4 ± 1.3, 1.0 ± 0.3 and -0.7 ± 0.6 t C ha^{-1} yr^{-1} for native forest, maize-fallow and soybean-fallow, respectively. In Site 2, they were 3.1 ± 0.7 and -4.0 ± 0.6 t C ha^{-1} yr^{-1} for the native forest and the soybean-wheat sequence, respectively. As C-escaled N_2O emissions were negatively related to C inputs and C budget, our approach allowed us to determine a threshold (around 1 kg N_2O-N per ton of C incorporated, for the Dry Chaco region), which indicated the amount of C input (around 5 tons of C) required to maintain soil organic carbon (SOC) levels (C budget equal to zero). These results highlighted the necessity of adopting an adequate crop rotation (at least two crop cycles of maize per cycle of soybean) or including service crops in the fallow period to ensure a higher income of C than is lost, reducing N_2O emissions per tonne of C entering.

Thus, coupling C and N cycles by means of C-scaled N_2O emissions proved to be a powerful tool for assessing production systems and for determining beneficial (or not) N_2O emissions and C inputs in this region. This work also proposes, when possible, to consider a native vegetation system to unmask the real impacts of agroecosystems.

Keywords: aboveground biomass, C sequestration, dry forest, rhizodeposition

A new Africa Carbon Flagship Program: accelerating progress towards achieving NDC targets

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Africa has the fastest population growth rates and is one of the most vulnerable continents to the adverse impacts of climate change. In response to these challenges, Africa will need to (1) increase the adaptive capacity of its agricultural systems, (2) Ensure promoted and adopted adaptation options have climate change mitigation co-benefits, and (3) create an enabling environment by pursuing transformational changes at different scales. In line with the Paris Agreement, several African countries identified the agriculture, forestry, and other land use (AFOLU) sectors as critical to achieving their Nationally Determined Contributions (NDCs) in climate change adaptation and mitigation. However, achieving the NDC targets is slow and constrained by knowledge, capacity, and financial gaps. In December 2023, Mohammed VI Polytechnic University (UM6P) and OCP Foundation partnered to launch an Africa Carbon Flagship Program (ACFP) aimed at accelerating progress towards achieving NDC targets. The ACFP intends to build on previous climate actions to address existing obstacles and barriers through a comprehensive approach that encompasses (1) Developing and disseminating cutting-edge knowledge and innovations to catalyze rapid progress towards fulfilling climate change adaptation and mitigation pledges and ensuring that actions are informed by the latest research and technological advancements; (2) Empowering individuals, communities, and institutions by developing and deploying effective practices, technologies, and mechanisms that promote transformational and lasting climate change resilience and action at different scales; and (3) Exploring support, and develop innovative financial mechanisms to facilitate the adoption of effective climate change adaptation and mitigation options by making them more accessible and financially viable. The program is designed for five years, with the first year dedicated to exploring the continent's historical and current climate actions. Concurrently, an ex-ante analysis will be commissioned to systematically map and evaluate AFOLU practices, their emissions, and the effectiveness of potential mitigation and adaptation strategies within the diverse contexts of African regions. The exploratory studies and ex-ante analysis will help to (1) Identify the regions of operations using a multi-criteria approach, (2) Identify strategic partners, and (3) Define the focus and expected outcomes of projects funded through the ACFP.

Keywords: Research, capacity strengthening, financial mechanisms, Africa, policy coherence

Camelina sativa L. cake Mitigate Enteric Methane and Ammonia Emission in dairy Polish Holstein Friesian heifers – preliminary results

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This study aimed to evaluate the effect of *Camelina sativa* L. cake, a source of C18:3 n-3, on enteric methane (CH_4) emission, ammonia production, dry matter intake (DMI), and ruminal fermentation. Eight Polish Holstein-Friesian heifers (369 ± 31 kg body weight) were allocated to two dietary groups (CON and EXP; n = 4) in a crossover design. Each period lasted 26 d, with a 21-d adaptation and 5-d sampling period (four days of gas analysis and one day of rumen fluid collection). The basal diet consisted of a TMR of grass silage (386 g/kg of DM), maize silage (208 g/kg of DM), beet pulp (119 g/kg of DM), rapeseed meal (133 g/kg of DM), meadow hay (119 g/kg of DM), and a mineral blend (35 g/kg of DM). Rapeseed meal (1 kg/day/heifer) was added to the basal dose (CON), while the EXP dose comprised 1 kg of *Camelina sativa* L. cake. Heifers were fed one time a day at 10.00 a.m. Feed intake was recorded individually during the entire experiment. Four respiration chambers (SPA System, Ltd., Wroclaw, Poland) were used for monitoring CO_2, CH_4, and ammonia emissions. On d 26 of each experimental period, samples of rumen fluid (500 mL) were collected by stomach tubing (Ruminator, Profs Products, Wittybreut, Germany) at 1 p.m. 3 hours after feeding. Immediately after collection, the pH of rumen fluid was measured using a portable pH meter and two subsamples were prepared for volatile fatty acids (VFA) and ammonia N determinations. For analysis of the rumen microbial community, rumen fluid was aliquoted into 2 mL tubes, snap-frozen in liquid nitrogen, and stored at −80°C until DNA extraction. The results showed that diet supplemented with 1 kg of *Camelina sativa* L. cake reduced methane (g CH_4/d) and ammonia emission (g NH_3/d) by 11% and 30%, respectively. The remaining analyses are in progress.

Keywords: rumen fermentation, linolenic acid, cattle, greenhouse gases

Optimized marginal cost curves for greenhouse gas emissions mitigation in Brazilian beef systems

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Animal husbandry is responsible for 6% of global anthropogenic greenhouse gas (GHG) emissions, while the proportion is considerably larger in Brazil (27%). As the world's second-biggest beef producer and the biggest exporter, the Brazilian beef sector alone makes up 18% of nationwide total GHG emissions. This suggests a high mitigation potential achievable from beef operations in Brazil, e.g., via improved diet formulation and feeding strategies, genetic selection, and also through improved pasture management which reduces animal life cycle and increases carbon sequestration in pasture soils. Marginal abatement cost curves (MACCs) have been frequently used as a tool to prioritize effective mitigation actions by explicitly comparing abatement potential with costs per tonnes of CO_2eq. However, the underlying methodology for MACCs is not standardized and a traditional MACC does not capture interaction among measures, i.e., when the adoption rate, cost and abatement potential of a measure is influenced by the adoption of other measures. We propose a bottom-up approach by using the EAGGLE bioeconomic optimization model at farm level to optimize the adoption rate of applicable and policy-relevant measures for beef production in the Brazilian Cerrado biome. The model maximizes farm profit subject to beef demand, pasture area projections with a detailed representation of a representative full-cycle beef production system at month times steps, allowing for seasonal variations in forage and herd composition for on-pasture and feedlot animals. The farm model optimizes pasture and animal management strategies, considering full life cycle assessment approach and changes in soil organic carbon sequestration. The model produces MACCs represented by cost-efficient frontiers of cost vs abatement potential (AP) using two cost metrics; implementation cost of measure (IC) and "real cost" (RC). The latter is represented by the change in gross margin due to the adoption of a measure relative to a baseline scenario. We model both animal efficiency measures, i.e., feedlots (FL) and pasture restoration (PR). By far, PR is the most cost-effective measure, with the largest AP and negative RC. We find that both IC and RC vary drastically depending on the mitigation target and adoption rate. For example, the IC of PR with the adoption rate required to reduce 5% of beef GHGs by 2030 is 200% higher than the IC for a 30% reduction target. We also show significant synergetic relations between adoption rates of measures. For example, the RC of PR is -US$27.5/ha/yr for 8MtCO2e/yr, whereas the RC of PR combined with FL is estimated as -US$33/ha/yr for 11MtCO2e/yr.

Keywords: MACC, climate change, farm modelling, pasture, land use

Assessing the cost-effectiveness of public investments in agriculture for climate mitigation

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Understanding the cost-effectiveness of various interventions and investments in agriculture is essential for informed decision-making to achieve climate change mitigation targets and other policy goals in the sector. However, robust evidence, particularly through independent impact evaluations, is scarce, especially in low and middle-income countries. While both the top-down and bottom-up modelling evidence for the cost-effectiveness of agriculture-related interventions is compelling, lack of impact evaluations of real projects with reliable costs data can influence decision-making.

Considering the long duration and evaluative challenges inherent in agriculture projects which have mitigation co-benefits, prospective ex-ante estimates of cost-effectiveness from development agencies and funds are a highly promising source of data for learning and analysing these interventions.

In this paper, we leverage a unique data set as an entry point into understanding the costs and effectiveness of climate mitigation within agriculture projects financed by the public sector. Since 2012, several International Financial Institutions (IFIs) follow a harmonized accounting approach to estimate GHG emissions from their agriculture and rural development projects. The EX-Ante Carbon-balance Tool (EX-ACT), developed by Food and Agriculture Organization of the United Nations (FAO) based on the Intergovernmental Panel on Climate Change (IPCC) TIER-1 methodology is consistently used by several IFIs to produce carbon mitigation estimates for these projects.

Using project data from IFIs and associated EX-ACT assessments, we construct a naïve, first-cut measure of cost-effectiveness for various publicly funded agriculture projects and their specific activities, benchmarking activity costs against their expected mitigation. Our study employs a systematic stratification approach to analyze a wide range of specific activities, including annual and perennial cropland management, rice cultivation, afforestation, forest degradation, grassland and livestock management, fisheries and aquaculture.

Based on the initial cost-effectiveness measures, we construct Marginal Abatement Cost Curves (MACCs) for these diverse range of activities. This enables us to evaluate the expected cost-effectiveness of individual agricultural activities and its magnitude of variance among several real-world projects. The initial results are consistent with existing literature on cost-effectiveness in agriculture. They indicate that the average cost-effectiveness varies across projects and within regions and depends on the methodological approach adopted and benchmark used (such as additionality considerations) in estimating emissions.

With growing policy enthusiasm in both public and private sectors to scale-up agriculture-based mitigation actions, we argue for a greater focus on impact evaluation in this space. Future comparisons can also benefit from greater methodological transparency and consistency.

Keywords: marginal abatement cost curves, cost-effectiveness, public investments in agriculture for climate mitigation, GHG accounting

Is organic farming sequestering carbon in soils?

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Organic farming is acknowledged as a farming system with multiple environmental benefits including lower greenhouse gas emissions when calculated per area basis. In organic farming systems no mineral fertilisers are applied but they rely on organic fertilisation and crop rotations with leguminous perennial crops such as lucerne. Both, organic fertilisation and perennial crops are known to enhance soil organic carbon (SOC) stocks and thus may lead to C sequestration and negative emissions when organic farming area is expanded. At European scale organic farming area is 10% of agricultural land and is aimed at being expanded to 25%. In Germany, currently 11% of agricultural area is under organic farming and the political target is 30% in 2030. Thus, the expansion of organic farming could create a significant C sink. However, there are increasing doubts on the role of organic farming for SOC formation.

Organic farming systems may rely on import of carbon into their soils from external carbon sources via organic amendments (e.g., compost). Such import is a transfer of carbon between sites but does not lead to C sequestration. Moreover, the lower yield in organic farming systems compared to conventional farms reduces the above ground plant residues that are left as feedstock for SOC formation in soils. Most plant residues in agriculture are below ground with roots and organic farming may foster root biomass more than conventional farms. Thus, the net effect of organic farming expansion on SOC stocks is under discussion.

We will present the state of art on the question if and how organic farming systems enhance SOC based i) on an extensive literature review on long-term field experiments and ii) on new assessments of large-scale soil data sets: The Agricultural Soil Inventory covering more than 3000 sites in Germany and a soil inventory of croplands on 74 organic and 75 conventional farms across Germany. The combination of such large-scale soil data sets together with plot scale data from long-term field experiments will allow a new assessment on the role of organic farming systems for carbon removal from the atmosphere with C sequestration in soils.

Keywords: C sequestration in soils, agricultural systems, organic farming, soil organic carbon, soil carbon inventories

Remote sensing of agricultural land use for enhanced climate policy implementation

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With the adopted amendment of the EU regulation 2018/841 on the inclusion of greenhouse gas (GHG) emissions and removals from land use, land use change and forestry (LULUCF), the EU member states agreed that – starting with the report in 2028 – the calculation of emission pools at national level should make use of geographically-explicit data. Earth Observation (EO) can support the implementation of the regulation by providing timely, seamless and high-resolution information for monitoring land use activities and land management practices related to GHG emissions and removals.

Frequently, EU-wide mapping initiatives that make use of data from the Copernicus program and derived products provided by the Copernicus Land Monitoring Service (CLMS) are complemented by national-level approaches that usually aim at generating more tailored datasets for specific monitoring requirements. In this context, the project KlimaFern, funded by the German Federal Ministry of Food and Agriculture, evaluates the potential of new EO-based national datasets on agricultural land use to enhance climate reporting in the LULUCF sector for Germany. We will present a proof of concept for the implementation of EO data in monitoring, reporting and verification (MRV) in the context of climate reporting and will outline first results of mapping area-wide GHG-related land use activities in agricultural land such as crop rotations, grassland conversion or planting of hedgerows and coppices. These products are derived on a national scale using state-of-the art machine and deep learning algorithms and multi-modal satellite image time series (e.g., Sentinel-1 and 2, Landsat, PlanetScope). All products are compared against available data and products at national level (e.g. agricultural statistics) to assess their potential for improving climate reporting and are evaluated in terms of quality, accuracy and consistency against existing and foreseen products of the CLMS.

The presentation will cover the conceptual framework and highlight challenges for a successful implementation of EO data for monitoring obligations taking Germany as an example. It will also point out synergies and relationships of climate related land use monitoring efforts with other policy initiatives at national and EU level. An in-depth view of the methodological development of the EO datasets will be provided by two accompanying poster presentations (Brög et al., Muro et al.).

Keywords: remote sensing, climate reporting, land use

Quantifying the Intensity of Greenhouse Gas (GHG) Emissions Using Inbred and Hybrid Rice under Two Different Field Management Conditions in the Philippines

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Rice is one of the most essential staple food in Southeast Asia and is especially significant in the Philippines. About one-third of the Philippines' arable lands are used for rice farming. Incidentally, in the Philippines, conventional rice is produced in soggy soil, which is among the most critical sources of anthropogenic greenhouse gases (GHGs) emission, particularly methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). Rice production in soggy soil produces GHGs because of the lack of oxygen in the soil, creating conditions conducive for GHG-emitting bacteria to flourish. Therefore, reducing GHG emission from rice becomes increasingly critical in Philippines. It was against these backdrops that the experiment was conducted. The experiment employed a split plot Randomized Complete Block Design (RCBD) using two factors (water management and type of rice variety). The treatments consisted of three (3) replicates. Factor A represented the water management approach and included two levels; A_1 - Continuously Flooded (CF) and A_2 - Mid-season Drainage (MSD). Factor B represented the different rice varieties under investigation. It included three (3) levels: B_1 - IR139216H (hybrid variety), B_2 - NSIC Rc480 (inbred variety), and B_3 - NSIC Rc222 (non-GSR inbred variety). Gas flux measurements were conducted using the static closed chamber method. The gas chromatograph utilized was SRI GC-8610C (SRI Instruments, CA USA) with a 63Ni electron capture detector (ECD) for N_2O analysis and a flame ionization detector (FID) for CH_4 analysis. The study also utilized Source-selective and Emission-adjusted GHG CalculaTOR for Cropland (SECTOR) to calculate the GHG emission. Result revealed that CF and MSD treatment maintained a desired standing water level of 5cm and above throughout the season. Also, the hybrid variety resulted in the lowest CH_4 emissions for both CF and MSD treatments, with values of 7,069 and 4,811 kg CO_2 eq ha^{-1} $season^{-1}$, respectively. In contrast, the inbred variety had the highest CH_4 emissions in the CF treatment, while the check variety had the highest in the MSD treatment. No significant differences were observed in N_2O emissions, which ranged from 123 to 168 kg CO_2 eq ha^{-1} $season^{-1}$ across all treatments. CH_4 accounted for 98-99% of the Global Warming Potential (GWP) in the CF treatment and 97-98% in the MSD treatment. In the CF treatment, the inbred variety had the highest total GWP of 17,776 kg CO_2 eq ha^{-1} $season^{-1}$. On the other hand, the hybrid and check varieties produced 7,192 and 14,264 kg CO_2 eq ha^{-1} $season^{-1}$, respectively. In the MSD treatment, the hybrid variety resulted in the lowest emissions with 4,953 kg CO_2 eq ha^{-1} $season^{-1}$ and significant grain yield of 6,986 kg/ha. The inbred and check varieties followed with emissions of 8,604 and 9,565 kg CO_2 eq ha-1 season-1, respectively. Implementing the MSD reduced GHG emissions for all varieties resulting in hybrid (19%), checks varieties (20%) and inbred (35%) reductions. The study recommends that using effective water management strategies along with hybrid rice varieties is a possible way to mitigate GHG emissions without comprising rice yield and income in Philippine.

Keywords: greenhouse gas emissions (CH4 and N2O), SECTOR, water management, continuously flooded (CF); mid-season drainage (MSD), checks varieties rice

A behaviour change perspective on food system transformation towards climate resilience and emission reduction

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Integrating agroecological practices such as cover crops, residue retention, or silvo-pastoral systems can increase sequestration of organic carbon in soils and vegetation. Decreasing production and application of in-organic fertilizers reduces emissions. There is evidence that a transition to agroecological approaches can substantially reduce agricultural GHG emissions. It remains a challenge to identify leverage points supporting such a transition. We present and apply a conceptual framework for analyzing individual and collective agency and behavior change in transforming agri-food systems (the ACT framework) by integrating multidisciplinary concepts including behavioral change models, Ostrom's social-ecological systems framework, and concepts related to agricultural innovation systems. Critical is the notion of 'opportunity spaces', which represent actors' resource access, power, and agency as well as of 'action situations' in which actors interact and make individual and collective choices among available options in light of expected benefits and costs of potential behaviors.

Drawing from case studies in five countries, we used the ACT framework to identify how and for whom agency and behavior change were enabled or impeded in past projects, programs or social movements related to agroecology. We reviewed process documents and interviewed case experts to identify assumptions in the theories of change.

Our findings indicate a strong focus on changing the behavior of farmers or other producers, most often through technical assistance, training, demonstrations, and other approaches. Supporting the adoption of technologies which increase carbon sequestration and reducing practices which create emissions is critical. However, in 46% of cases there were reports of the interventions being poorly aligned with actor needs. The behaviors of consumers and governance decision-makers were least often considered and addressed, being targeted in less than a quarter of cases. Structural approaches to influence agency and behavior change, such as addressing barriers imposed through social norms and relations, and/or resource, economic or governance systems, were uncommon. In contrast, case experts, expressed that market and value chain linkages, partner and institutional support, social learning and collaboration among actors, and efforts to address power and agency in multi-stakeholder engagements were key influencing but hardly targeted factors to enable behavior change towards agroecological principles.

Based on the results from our review, we developed recommendations that can guide future efforts to enable agri-food systems transformation through actors' agency and behavior change. These include: i) investigating the factors influencing agency and behaviors across agri-food system actors during an initiative's design phase; ii) co-developing with the agri-food system actors the vision for their agri-food system integrating implications on GHG emissions; iii) developing a clear Theory of Change that lays out the steps from current situation to the envisioned change, along with clear descriptions of the behavioral assumptions embedded in each step; and iv) implement and reflect on progress in an inclusive, participatory, and iterative way.

Keywords: conceptual framework, behavioral change, agroecology, food systems, transformational change

Climate change induced heat and drought stress hamper climate change mitigation in German cereal production

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Introduction

Agricultural production and climate change strongly influence each other and there are significant efforts to minimize negative impacts in both directions. In particular, breeding progress has succeeded in reducing the carbon footprint (CFP) of cereals over time (Riedesel et al., 2022). However, there is widespread certainty that climate change-related weather extremes have led to stagnation of cereal yields in many global production regions. We assume that climate change-related yield stagnation is also evident in variety trials in Germany, which has to date only been shown for on-farm yields. Furthermore, we expect that the stagnation in yields also leads to a stagnation in the downward trend of CFP, and that heat and drought stress in particular increase the CFP of cereals. In addition, we hypothesize that the site-specific soil quality largely determines stress induced increases in CFP.

Materials and methods

We conduct a partial life cycle assessment (LCA) with German variety trial data from 1993 to 2021 and determine the greenhouse gas emissions per unit of land (GHGL), as well as the CFP of winter wheat, winter rye, and winter barley. Further, we evaluate the time trends of yield, GHGL, and CFP using linear and quadratic plateau models. In addition, we calculate spatio-dynamic weather indices (WIs) for moderate, severe and extreme heat and drought stress. Using mixed models, we estimate the explanatory power and effect size of heat and drought WIs on the CFP. Finally, we present the spatial differences of heat and drought on the CFP at different soil qualities.

Results and discussion

We show yield plateaus in all crops and stagnating GHGL trends, resulting in a stagnation of the downward trend of CFP, especially for rye and barley. We highlight that heat and drought increase the CFP of all crops. However, the impact of heat and drought on the CFP varies greatly with soil quality across all crops. We conclude that climate change-induced weather extremes are major challenges not only for cereal production and food security but also for climate change mitigation in the agricultural sector, highlighting the importance of high-yield locations, alongside variety selection and resource-efficient management, for climate change mitigation. This study is the first that proves yield stagnation in German variety trials. Moreover, this study is the first to analyze the impact of heat and drought stress on cereal CFP, a crucial aspect of climate change mitigation in field crops.

References

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Keywords: carbon footprint, wheat, rye, barley, heat, drought, LCA, soil quality, variety testing

Economic and social valuation of climate change mitigation strategies in livestock systems

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Socio-ecological systems are framed from a human-in-nature perspective. Human societies are embedded in the dynamics of ecological systems and must survive, co-evolve, and thrive within the limits imposed by the ecosphere. Natural systems produce ecosystem services for human beings, while social systems intervene in natural systems with positive (environmental benefits) and negative externalities. Along with crops, livestock production is one of the economic enterprises that humans engage for their livelihoods using the natural ecosystem while also providing ecosystem services and environmental benefits. Livestock systems embrace all aspects of the supply and use of livestock and livestock products, including the distribution and abundance of livestock, the different production systems in which they are raised, estimates of their current and future production and consumption, the people engaged in livestock production, and the benefits and impacts of keeping livestock. Carbon storage and capture is an ecosystem service present in livestock systems with cultivated forages, rangelands, and agro-silvopastoral systems. While humans, through consumption, put pressure on natural ecosystems, they also develop, and introduce policy, institutional, and technological innovations, which have the potential to decrease methane emissions from ruminants. Therefore, such interventions have great potential to ensure sustainability of the natural systems and hence the social systems because the combination of carbon storage and capture and reduction of methane emissions in livestock systems generates a better carbon balance, and hence reduces the associated adverse impacts on climate change. While there is evidence for the technical efficacy of these interventions, the cost of inaction, the investment required for implementing them and its economic viability, and their impacts if implemented at large scale are not fully known, thereby limiting our ability to promote their financing. In this study, we aim to formulate a viable method for the economic and social valuation of benefits of action to implement interventions that enhance carbon storage and capture and reduce methane emissions in livestock systems. For the economic valuation we employ market pricing methods. The market pricing method consists of consulting carbon prices in the world's main Tradable Emissions Permit Systems and the economic instruments for emissions regulation used in the country where the evaluation is carried out. For the social valuation, it is necessary to determine the level of knowledge and perception of the stakeholders on the topic. To achieve this, we inquire whether individuals are familiar with the concepts of carbon storage, capture, and methane emissions reduction. We assess their perception of the significance of these measures and use contingent valuation methods, including Discrete Choice Experiments and Public Goods Games, to estimate their willingness to financially support mitigation strategies. We have currently implemented this strategy in three studies in Colombia to evaluate the reduction of methane emissions in silvopastoral systems with improved pastures and the reduction of the carbon footprint in meat and milk production. Our findings show favorable outcomes where the environmental value prevented from being lost or newly generated due to interventions surpasses the costs associated with implementing them.

Keywords: carbon storage and capture, reduction of methane emissions, economic and social valuation, mitigation strategies, livestock

Implementation of the German peatland monitoring program for climate protection - Open Land

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Peat and other organic soils store large amounts of soil organic matter, which is highly vulnerable to drainage. Thus, drained organic soils contribute around 7% to the total German greenhouse gas (GHG) emissions and around 44% to the emissions from agriculture and agriculturally used soils, despite covering less than 7% of agricultural area in Germany. With approximately 90% of the total emissions, carbon dioxide (CO_2) is the most important GHG with regards to drained organic soils. To evaluate possible GHG mitigation measures such as classical re-wetting, paludiculture or adjusted water management compared to the still widespread *status quo* of drainage-based peatland agriculture, an improved data set on GHG emissions, in particular CO_2, and their drivers is needed. Furthermore, spatial data and upscaling methods need to be improved.

To meet these needs, a long-term monitoring program for organic soils is currently (2020-2025) being set up for open land at the Thünen Institute of Climate-Smart Agriculture. A consistent long-term monitoring of soil surface motions, representatively covering a broad range of organic soils and land use types will be combined with the repeated measurement of soil organic carbon (SOC) stocks to assess CO_2 emissions using standardized and peat-specific methods. Land use types comprise grassland, arable land, paludiculture as well as unutilized re-wetted and semi-natural peatlands. At each of the envisaged approximately 150 monitoring sites important parameters such as groundwater table, vegetation and soil properties are monitored. Together with the updated map of organic soils, all collected data form the basis for improving regionalisation approaches for drivers – particularly water levels and SOC stocks – and CO_2 emissions from organic soils in Germany. Here, we will present the general structure of monitoring program, the current state of site establishment as well as first results.

Keywords: monitoring, organic soils, surface motions, carbon stocks, hydrology, vegetation, management, regionalisation

The impacts of conservation agricultural practices on soil greenhouse gas emissions in maize production systems in Buea, Cameroon

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Greenhouse gas (GHG) emissions from the agricultural sector in Africa are among the fastest-growing emissions in the world. Finding conservation agricultural practices that ensure food security and reduce the carbon footprint is one of the biggest challenges facing Africa's agriculture. This study aimed to investigate the effects of some conservation agricultural practices (reduced tillage practices and organic fertilization) on soil GHG (CO_2, N_2O, and CH_4) emissions in two growing seasons (2020 and 2021). The study used a split-plot design to evaluate the effects of zero tillage (No Till) and conventional tillage (Till) and fertilizer application types, including zero fertilizer (CON), synthetic fertilizer (Urea)(SYN), and organic fertilizer (composted municipal solid waste) (ORG), on the above GHGs. The field experiment was conducted at the University of Buea in the Southwest region of Cameroon and used the hybrid maize cultivar CMS 8704 as the test crop. The static flux chamber method was used to measure the impacts of tillage and fertilizer types on soil GHG emissions. The HMR package of the R software was used to calculate the flux rate of each of the three GHGs. To visualize the data and assess the significant differences in GHG emissions using ANOVA, the grammar of graphics (ggplot2) and agricolae packages in the R programming language were used. The results show that in the first growing season, cumulative N_2O was released in the following order: No Till:SYN > Till:ORG > No Till:CON > Till:CON > Till:SYN > No Till:ORG, while cumulative CO_2 was released in the following order: Till:ORG > Till:SYN > Till:CON > No Till:CON > No Till:ORG > No Till:SYN. On the other hand, CH_4 was released in the following order: Till:CON > Till:ORG > No Till:SYN > Till:SYN > No Till:CON > No Till:ORG, although all the values were negative, indicating that the upland soils of the study area consumed methane. Tillage practice and fertilizer types significantly affected ($p < 0.05$) GHG emission in 2020. In the 2021 study season, N_2O was emitted in the following order: Till:SYN > No Till:SYN > No Till:ORG > Till:CON > Till:ORG > No Till:CON, while CO_2 was emitted in the following order: Till:ORG > No Till:SYN > Till:CON > Till:SYN > No Till:ORG > No Till:CON. Although No Till:ORG recorded positive CH_4 values, most plots still recorded negative CH_4, indicating that most of the plots acted as sinks for methane in 2021. Tillage practices and fertilizer types also significantly affected ($p < 0.05$) GHG emissions in 2021. GHG emitted in the 2020 season was significantly ($p < 0.05$) in 2021 compared to 2020 due to changes in weather conditions between the two study periods, which resulted in fluctuations in soil moisture and temperature. The authors recommend the use of reduced tillage practices with the application of organic fertilizer for reducing GHG emissions in agricultural soils. Also, further studies should be conducted on the impacts of different fertilizer application rates and combinations on GHG emissions for an extended timeframe beyond two years.

Key words: greenhouse gas emission, conservation agriculture, tillage practices, fertilizer application.

Barley monoculture versus Barley with undersown species: impact of diversity on GHG exchange in Finland

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Agricultural land use has a major impact on the environment by representing ca. 38% of the Earth's land surface and 17% of total anthropogenic greenhouse gas emissions. While the intensification of agriculture has improved food security, it has also harmed the environment in many aspects.

There are practices which could be less harmful for climate and biodiversity. For example, climate-friendly practices can help increase carbon sequestration and reduce CH4 and N2O emissions. However, there is a need 1) to quantify and verify the impact of these practices with traditional practices and 2) to estimate the size of the possible impact.

To bridge part of this knowledge gap, the TWINWIN experiment was established in Helsinki in June 2019. TWINWIN's goal was to study the impact of diversity on various soil-plant-atmosphere variables such as soil micro-organisms, greenhouse gases, plant diseases, and many more. The experiment consisted of 60 plots where barley was sown as monoculture or with 1 to 8 undersown species: *Lolium perenne, Phleum pratense, Trifolium hybridum, Trifolium repens, Medicago sativa, Trifolium pratense, Festuca arundinacea and Cichorium intybus*. The eight undersown species varied in functional traits, such as rooting depth and nitrogen-fixing properties.

GHG measurements were conducted on 26 plots, which included barley monoculture, barley + 1, barley + 4 and barley + 8 undersown species and bare fallow. CO2 fluxes (light response of net ecosystem exchange and total respiration), CH4 and N2O net fluxes were measured over three summers and two winters, with intervals varying between twice to once a month. In addition, various soil and vegetation parameters were measured simultaneously, such as soil temperature, soil moisture, green area index, above ground biomass and yield.

Here, we will present the TWINWIN experiment with a focus on CO2, CH4 and N2O fluxes measured with the chamber technique from 2019 to 2022. No significant differences were observed between treatments regarding CH4 and N2O fluxes, except for a few days with no distinct patterns. However, significant and notable differences were observed between barley monoculture and barley with undersown species regarding CO2 fluxes, especially outside the growing season.

Keywords: barley monoculture, undersown species, GHG, diversity, Nordic country

Breeding more sustainable plant varieties

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Balancing sustainability with food security is essential for ensuring a resilient and thriving environment for future generations. Crop production has huge impacts on biodiversity, ecosystem functioning, and human welfare. Currently, food production accounts for approximately 26% of global greenhouse gas emissions, 32% of acidifying emissions and 78% of eutrophying emissions. It uses 43% of all habitable land and 70% of freshwater withdrawals (Poore and Nemecek, 2018). However, we also need to increase food production by 60% to feed a population of 9.7 billion people by 2050 (Godfray et al. 2010). Consequently, we need better ways to breed plant varieties that ensure we have a sustainable food production system, without compromising food security.

Current crop breeding objectives encompass a range of goals aimed at enhancing productivity, resilience, and quality. For example, breeding objectives often include improving yield potential, disease resistance, tolerance to environmental stresses such as drought or heat, nutritional value, flavor, shelf-life, and other traits that meet consumer preferences and market demands. Modern plant breeding has successfully driven significant genetic gain in these traits over the past decades.

However, plant breeding programs have not made significant progress in reducing the environmental footprint of plant varieties, although there are genetic traits that can reduce the environmental impact of new plant varieties. For example, improving nitrogen use efficiency can reduce acidification, eutrophication and GHG emissions; water use efficiency can reduce water consumption; and disease resistance can reduce chemical pollution and biodiversity. It is difficult to measure the impact of these genetic traits on sustainability, thus they are difficult to include in selection decisions, leading to them being overlooked in current breeding strategies. Consequently, there exists a crucial gap in the methodology that would allow these environmental concerns to be addressed by plant breeding programmes.

A methodology has been developed to quantify the independent effect of genetic traits on different environmental externalities. We defined six different environmental externalities, inspired by the planetary boundaries model (Steffen et al., 2015): land use, water use, eutrophication, acidification, chemical pollution, and greenhouse gas emissions. This approach goes beyond just GHG emissions, to give plant breeders a more detailed understanding of the total environmental footprint of potential new varieties. This methodology enables plant breeders to calculate externality or environmental coefficients for traits and include them in plant breeding programs. Environmental coefficients have been successfully used in animal breeding programs to develop selection indexes that reduce methane emissions (Richardson et al. 2021, Amer et al. 2017, Quinton et al. 2017). Plant breeders can use this tool to rank candidates, quantify their environmental footprints, and select the most promising candidates. Farmers can also use this tool to choose varieties that allow them to reduce their environmental footprint whilst also maintaining their profit. Integrating sustainability into plant breeding decisions will be imperative for the long-term viability of food production systems.

Keywords: plant breeding, environmental footprint, food security, agricultural emissions

Costs of greenhouse gas mitigation measures applicable to the Swiss agricultural sector

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To combat climate change, ambitious net-zero emission targets have been announced by many countries. In Switzerland a climate law to reach net-zero by 2050 has been approved in 2023 by the Swiss population. Agriculture, acting as both a source and a sink for greenhouse gas (GHG) emissions, could play an important role to reach this goal. Since 1990 Swiss agricultural GHG emissions have been reduced by 13% and currently account for 14% of the total emissions. The new target foresees a reduction by at least 40% for the agricultural sector compared to levels in 1990.

Agricultural efficiency measures that were previously applied in Switzerland (reduction of livestock numbers and nitrogen fertilizer inputs, breading for increased production efficiency) have reached a limit, especially due to challenges for food security and farmers' willingness to implement measures. Therefore, a realistic analysis is required to identify additional, promising mitigation measures, that have a significant potential, are socially acceptable and cost-effective. In this context, a critical but often neglected aspect is the economic cost with special emphasis of the farmers' perspective. Such costs not only include investments costs in technology, but also more hidden costs like enhanced workload or costs for training.

Currently, many marginal abatement cost curves (MACC) show significant mitigation potentials at negative costs. Still, progress in reducing agricultural GHG emissions in practice fall short as compared to these promises. This underlines the role of farmers personal perceptions for the final effectiveness of mitigation measures in practice. This again calls for a holistic cost analysis that will help develop new climate policies which trigger farmers' decisions to implement new measures (e.g., through subsidies).

With this study, we aim to contribute to such a cost analysis. First, we searched for promising mitigation measures suitable for Switzerland. For this purpose, we took into consideration the GHG mitigation potential of measures, their popularity and social acceptance, farmers' operational difficulty, and policy support. The following GHG mitigation and carbon sequestration measures have been identified: biochar, agroforestry, rotation with more legumes, nitrification inhibitors, feed additives, increasing lactation number, covering slurry containers, biogas plants, and trailing hose for manure spreading. Second, we will analyse the cost of each identified measure from the farmers' implementation perspective, accounting for detailed changes in activities linked to the implementation of specific measures. We will consider information from various sources including grey literature, real markets and expert knowledge if necessary. Third, we will identify explanations for cases where costs of measures are highly variable. We will discuss the nature of different cost types and how they influence implementation of the measures. With this, the study shall provide new insights in the general discussion of GHG-mitigation costs. Finally, the results will conclude in realistic and holistic GHG mitigations potentials in the future. We believe that the results of this study will be of critical importance to land managers and policymakers aiming to reach the net-zero target.

Keywords: net-zero, mitigation measures, costs, carbon sequestration emission reduction

AgNav: A digital sustainability platform for farming systems in Ireland

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The global agricultural sector is faced with the complex challenge of meeting the demand of the growing population while also mitigating its impact on the environment and ensuring economic viability of farming systems. In Ireland, targets have been established for greenhouse gases, air pollutants, water quality, and biodiversity, all of which are closely associated with the agricultural sector. National action plans have been published to provide pathway on achieving such targets. However these plans are at a national level. To achieve these national targets adoption of practices/technologies needs to occur at farm level. To address this, AgNav, a new farmer and advisor orientated digital sustainability platform is being developed. AgNav is a sectoral wide collaboration between Teagasc, Bord Bia, and the Irish Cattle and Breeding Federation (ICBF). The objective of the AgNav platform is to encourage and support farmers in implementing climate action and sustainability improvements on farm. This is achieved by conducting robust sustainability assessments of farming systems, and creating tailored farm action plans. This in turn provides a mechanism for measuring and communicating progress towards national targets. There are three stages to AgNav; Assess, Analyse, Act. Through years of research Teagasc have published life cycle assessment (LCA) models for agricultural production systems. These Teagasc LCA models are the underpinning methodology in AgNav and have been integrated into the national cattle database in ICBF. Through data integration, farm activity data collected through the Bord Bia Quality Assurance Scheme is collated with ICBF data, allowing LCA of individual commercial farms to be conducted. This establishes a benchmark a given farm (Assess). The LCA calculates GHG and ammonia emissions on per farm, per hectare, and, per unit product basis. To provide transparency, activity data used in the LCA is summarised and present to user. A live decision support tool has been developed on the AgNav platform. This interactive tool presents the user with a range of mitigation strategies and allows the user to see their potential impact at varying adoption rates. The mitigation strategies presented are those identified by Teagasc's Marginal Abatement Cost Curve (MACC) and the national climate action plan to ensure consistency in communication. This process allows the user to identify which actions to prioritise for their farming system (Analyse). Utilising this knowledge advisors and farmers can co-create a farm specific action plan. This provides farmers a path on what actions can be adopted. It also provides a mechanism to review action plan progress. The AgNav platform is currently being piloted through the Teagasc SignPost advisory programme, a free, voluntary advisory programme to support climate and sustainability actions on farms. As of April 2024 3,734 farm plans have been created with an average of 4 actions per plan. AgNav is seen as being a central tool for future knowledge transfer in the Irish agricultural sector, as it aims to expand its scope to all major enterprises, all farms, and report multiple sustainability indicators.

Keywords: life cycle assessment, beef, dairy, GHG mitigation

Economic evaluation of accounting subsoil carbon stocks in the context of carbon farming

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Carbon farming protocols commonly account for soil organic carbon (SOC) in topsoil which is often argued to contain the largest SOC stocks in agricultural soils. In tropical conditions, deeper soil layers may have significant and dynamic SOC stocks, leading to a necessary change in accounting standards. This study estimates deeper SOC stocks (60-100 cm) using soil data from the PRO-Carbon collaborative project between Embrapa and Bayer Crop Science, covering detailed soil data of 53 farms from 11 Brazilian states, and evaluates the costs for quantifying SOC stocks against possible economic gains from carbon crediting.

Accordingly, the study offers an optimization framework for protocols of agricultural SOC monitoring and prediction based on the value of information approach. Soil carbon data indicate considerable SOC stocks in deeper layers in tropical soils of Brazil, on average 55% of SOC stocks are found below 30 cm within 1 meter depth. Preliminary economic analyses show that in most cases, carbon quantification costs are paid off even at low carbon prices simulated (1—5 USD per tonne of CO2eq). However, high profitability of accounting deeper carbon stocks are mostly limited, being sensitive to several factors, above all, the sample size prescribed in protocols and the type of remuneration schemes assumed. Beside conventional carbon quantification methods remain costly, there is also a potential scalability challenge of the technical infrastructure and personnel in the study region, which is beyond the scope of this study. Nevertheless, preliminary results indicate costs for SOC estimations in subsoil SOC stocks can be reduced when the integration of data-model fusion procedures are improved, i.e., coupling conventional carbon quantification methods with alternative estimation approaches utilizing statistical and SOC dynamic modelling together with data assimilation.

Keywords: carbon trading, MRV, value of information, carbon sequestration, climate change mitigation

Exploring the Role of Water, Carbon, and Nitrogen Dynamics in Wet Grasslands for Greenhouse Gas Mitigation: A Process-Based Modelling Approach

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Introduction

Wet grasslands, situated on the fringe of ascending groundwater, exhibit high sensitivity to fluctuations in water table depth. These fluctuations trigger rapid shifts in vegetation and soil turnover processes. While wet grassland sites serve as significant carbon sinks, excessive drainage and intensive agricultural practices have resulted in substantial losses of stored carbon into the atmosphere, leading to increased greenhouse gas emissions. Furthermore, the dynamics of carbon and nitrogen are intricately linked in wet grassland ecosystems. Nitrogen availability can influence carbon sequestration rates, and vice versa, highlighting the importance of considering both elements in ecosystem management. To effectively mitigate greenhouse gas emissions, it is imperative to conduct comprehensive investigations into the simultaneous dynamics of water, carbon, and nitrogen under varying water table depth management scenarios. By understanding how these factors interact and influence each other, we can develop more targeted strategies for wet grassland conservation and restoration, ultimately reducing carbon loss and mitigating greenhouse gas emissions. Several studies have examined individual components of water, carbon, and nitrogen dynamics in wet grasslands. However, a comprehensive investigation of these variables and their complex interconnections is still lacking. Therefore, this study was initiated to utilize a process-based model capable of integrating all interactions between soil, plants, and the atmosphere. Its objective is to explore the dynamics of water, carbon, and nitrogen in wet grasslands, with the goal of validating its utility as a tool for future climate studies to assess strategies for rewetting wet grasslands as a means of mitigating greenhouse gas emissions.

Material and method

To test different water table depth treatments on wet grasslands, we employed the data from a lysimeter station in the Spreewald wet grassland, featuring four lysimeters with different groundwater level management practices. There was a weather station installed in the lysimeter station records the meteorological conditions. We had two time cut each year and the above-ground biomass is measured after each cut, and various parameters including evapotranspiration, gross primary productivity, ecosystem respiration, nitrogen amount in biomass, nitrate leaching, and N_2O are monitored. The MONICA process based model (Model for Nitrogen and Carbon in Agro-ecosystems) was utilised in this study. To optimise the model results the SPOTPY algorithm was used.

Results

We have categorized the data into three parts: the crucial components of the water cycle, including evapotranspiration; the contents of the carbon cycle, comprising gross primary productivity and ecosystem respiration; and the nitrogen content in biomass, nitrate leaching, and N_2O emissions, representing the nitrogen balance in the wet grassland site. MONICA has successfully replicated essential variables within wet grassland ecosystems, demonstrating good performance with rRMSE ranging from 0.20 to 0.76 and Willmott's Refined Index of Agreement $dr \geq 0.35$ in all instances. This confirms its ability to simulate the effects of environmental or

management changes, particularly those related to alterations in surface-near groundwater conditions. The model's accurate representation of critical variables underscores its suitability for thorough evaluations in dynamic ecological scenarios for future GHG mitigating studies.

Keywords: wet grasslands, MONICA, SPOTPY, carbon sink

Developing Hi-sAFe-machine learning hybrid approach as a field-specific decision support system for agroforestry systems

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Introduction

Germany has set a goal to become carbon neutral by 2045, and significant work remains, particularly in the agriculture sector. Agroforestry systems (AFS), which cultivate perennial woody plants alongside annual crops or grassland on the same plot of land, can aid in the agricultural sector's efforts to combat climate change. In Germany, the planting of wood strips has proven to be a promising AFS. AFS can operate as carbon sinks, sequestering carbon in the woody strip both directly in the biomass and indirectly by increasing soil humus content. According to (Beillouin et al., 2023), AFS are the most effective agricultural measure for increasing organic soil carbon content in proportion to area. Simultaneously, the tree strips deplete productive territory for food and fodder production. Furthermore, the establishment, maintenance, and harvesting of the tree strips incurs additional expenditures and emits greenhouse gases (GHGs). Agroforestry systems differ from simply arable farming systems in terms of wind speeds and evapotranspiration dynamics (Markwitz et al., 2020). The impact of tree strips, particularly shadowing on nearby arable crops, can be either favorable or harmful, depending on location, weather, and species selection. AFS's potential as a potentially sustainable and climate-friendly growing system is assessed using individual system experience and measurement findings. So far, there has been a paucity of decision-making tools for agricultural advice and assessing the actual climate protection potential. The creation of a field-specific decision support system (EUS) for AFS that evaluates the cultivation and climate protection potential of various systems should assist to close this gap. The Hi-sAFe model is a 3D model uses competition and facilitation, which are significant mechanisms explaining positive biodiversity-productivity relationships in biodiversity ecosystem functioning research, even though it does not explicitly incorporate biodiversity as a driver for outcomes like crop yield. In Hi-sAFe, the forcing variable is the daily macroclimate, and the model computes itself some of the variables in the microclimate. Then, the effect of trees on air temperature, relative humidity, and wind speed was not considered. Therefore, accurate dataset of soil moisture, soil temperature, ET, yield, biomass at different distances from the trees, will be used to validate Hi-sAFe. Such individual limitations will be addressed by integrating these models in an ensemble approach. Data-driven tools, such as machine learning (ML) can play an important role in dealing with large and complex datasets in agroforestry systems in a variety of ways, including data processes and analysis, predictive modeling, geospatial data generation, monitoring environmental impacts, and scaling operations. Machine learning approaches are increasingly being used as data-driven tools to extract patterns and insights from the ever-increasing stream of geospatial data (Reichstein et al., 2019), but they have received less attention thus far in AFS.

Materials and Methods

Following extensive review, we found that the existing DSS lacks decision-making aids for cultivation recommendations and assessing actual climate protection potential, gaining different limitations (Figure 1). The Hi-sAFe agroforestry model (Dupraz et al., 2019) outperformed other models offering a unique 3D and spatially explicit framework to analyze tree-crop competition for light, water, and nitrogen. Incorporating factors such as climate, soil characteristics, species interactions, and management practices, HisAFe provides a comprehensive

platform for understanding the complexities of agroforestry systems. The KlimAF project is developing an EUS that will combine Germany-wide area-specific soil data from the BüK200, meteorological data from the DWD at 1km2 resolution, and high-resolution data on slope inclination and exposure. A tree inventory is being created, which will include key parameters for relevant tree species such as target height and diameter, crown form and light absorption, and leafing and defoliation phases. Microclimatic impacts, such as radiation (shading), temperature, humidity, and wind, depending on the distance to the wood strip and strip orientation, as well as the width, height, and density of the wood strip, are simulated in daily time steps for different woody constructions.

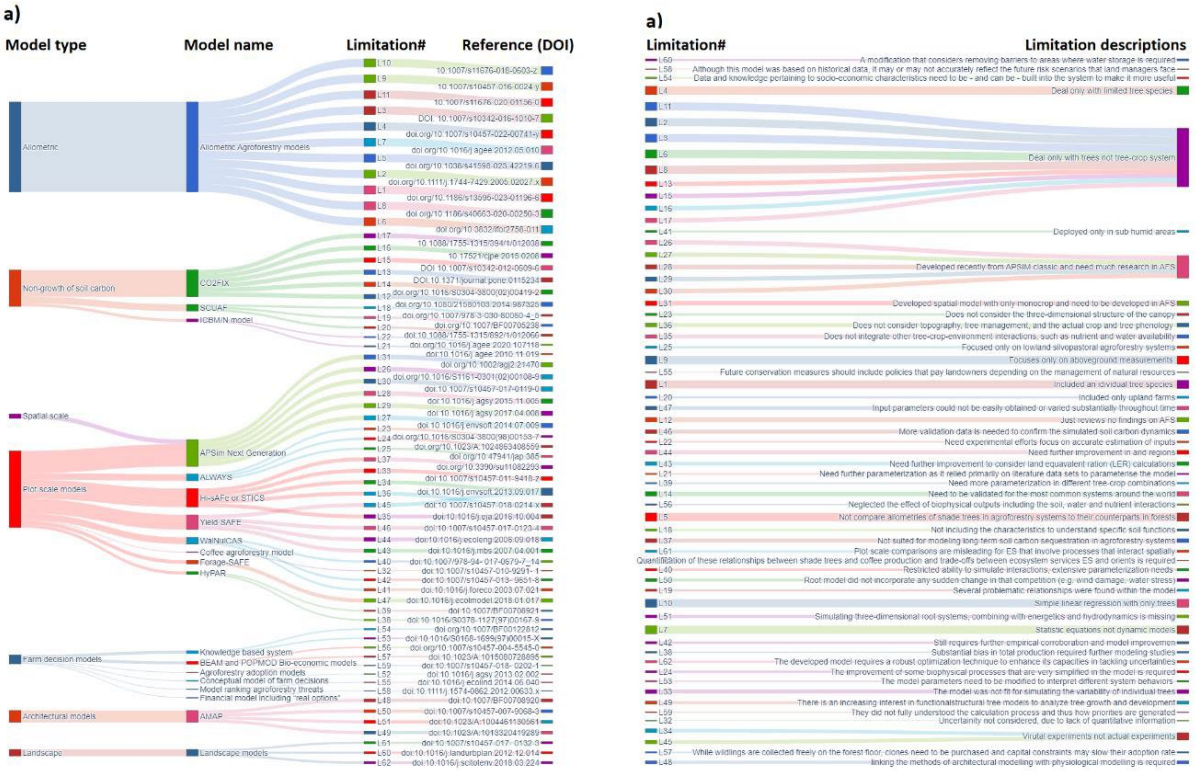

Fig.1 Current agroforestry models and their limitations. (a) Represents the main group of the models (model group), the name of model in each group, the limitation number and the related reference as DOI. (b) Represents the main description of limitations for each limitation number. The thicker the node and arrow the larger number of limitations.

Results and Discussion

The model was parameterized using soil, weather, and crop rotation dataset for both agriculture control and within strips of fast-growing poplars alternating with narrow (48 m) and wide (96m) crop alleys established in 2008 in Northern Germany at Wendhausen. Multi-year (2009-2016) crop yield of oilseed rape and winter wheat in the narrow and wide crop alleys at different spaces from trees (0, 1, 4 and 7 m) were used in parameterizing Hi-sAFe. Since the model couples the pre-existing STICS crop model (Brisson et al., 2003) with a new tree model, we calibrated STICS for diverse crops in the agriculture control. To ensure, deploying the model at spatial explicit in different environment, we integrated the Hi-sAFe model with machine learning algorithms such as Artificial Neural Network (ANN) and Convolutional Neural Network (CNN) for simulating yield and GHG in AFS at a robust and spatially explicit scale, allowing for a global assessment of GHG reduction potential. Combining Hi-sAFe with machine learning in a hybrid approach offers a promising approach for advancing agroforestry simulations. By leveraging the strengths of both techniques, we can gain a deeper understanding of complex interactions within these systems and optimize their management for improved productivity and sustainability at scale.

Conclusion

The combination with life cycle analysis allows for a comprehensive climate balancing of agroforestry systems. Long-term yield data and data on the growth of wood strips are available to help build the model chain. The current approach combines Hi-sAFe with machine learning to fill the limitations of the past data driven tools, dataset, and models, creating a robust DSS for agroforestry systems. The EUS is designed to allow farmers and consultants across Germany to virtually create a wide range of agroforestry systems on their property, as well as find the best sites and methods for maximizing productivity and climate protection performance.

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Keywords: agroforestry, alley cropping, poplars, crop rotation, life cycle assessment, winter wheat, oilseed rape, shade, climate protection

Assessing economic value, trade-offs, and synergies of ecosystem services from sustainable agricultural practices in India

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Conventional mainstream agriculture, although helpful in addressing food and nutritional security, has also been responsible for surpassing planetary boundaries. Hence, developing sustainable and ecological-based food production systems is crucial to address the climate change impacts and simultaneously enhance ecosystem services. Agriculture is multi-functional, producing economic goods including food, feed, fibre, and fuel, as well as providing several intangible or non-tradable services to society free of cost. However, farmers are not fully compensated monetarily for the benefits of the several non-tradable services they provide through agriculture. Therefore, recognizing the monetary value of non-tradable ecosystem services is crucial to incentivize farmers to adopt eco-friendly technologies and practices for the sustainable development of agriculture.

This study attempts to estimate the value of ecosystem services by using direct and indirect valuation methods—for example, carbon sequestration, methane emission, nutrient availability, biological nitrogen fixation, and water saving—generated by several important technological and agronomic interventions, namely the direct seeding of rice (DSR), zero-tillage in wheat, leguminous crops, organic manure, integrated nutrient management, and agroforestry, based on studies conducted in India. It also explores the trade-offs between the non-tradable and tradable ecosystem services attributable to these interventions. A total of 4726 pair-wise observations from 1104 studies were included using the meta-analysis framework.

In general, the response of improved agricultural practices to ecosystem services was largely positive and has the potential to enhance several key ecosystem services. However, the magnitude of ecosystem services varies among the practices. Further, not all the agricultural practices generate win-win outcomes. No-tillage, legumes, and integrated nutrient management had win-win outcomes, whereas trade-offs were evident in the cases of direct-seeded rice, organic manure, and agroforestry. Nevertheless, the implementation of improved agricultural practices has the potential to provide an enormous value of positive externalities to society. The monetary value of the non-tradable services resulting from most of these interventions is quite large, 34–77% of the total value of all the ecosystem services.

Overall, improved farm practices emerged as promising eco-friendly and sustainable strategies to achieve the Sustainable Development Goals (SDGs) that are inherently linked with agriculture. Our study has clear policy relevance. The direct implication emerging from our study is to incentivize farmers to adopt technologies and practices that are sustainable and conserve ecosystem services. One possible strategy to achieve this is by transforming existing agricultural incentive structures that currently support unsustainable patterns of production. In this regard, the gradual phasing out of fertilizer subsidies while providing income support that encourages farmers to adopt nature-based farming practices could be part of the repurposing strategy. The outscaling of improved farm practices must be integrated with R&D investments in developing supportive agricultural technologies and infrastructure.

Keywords: ecosystem services, improved farm practices, economic value, trade-offs, meta-analysis, India

Quiet Heroes of the Desert: The Camel's Modest Contribution to Global Greenhouse Gas Emissions from Livestock

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The population of Old-World Camelids, known for their resilience and essential role in sustaining livelihoods in challenging environments, has nearly doubled over the past twenty years. Despite their burgeoning populations, camels have remained largely overlooked in global assessments of greenhouse gas (GHG) emissions. This study introduces the preliminary Tier 2 assessment of direct emissions from the global camel population in 2015, with projections up to 2030 and 2050 under a business-as-usual scenario (BAU). The research incorporates data from FAOSTAT, literature and the DYNMOD herd model to deduce herd structure and calculate cohort-specific energy requirements and feed intake, adhering to IPCC 2019 guidelines and GLEAM methodology. The assessment reveals that camels were responsible for an estimated 65 Mt CO2eq of direct GHG emissions in 2015, which equates to 1.8% of the direct emissions attributed to the livestock sector globally. The majority of these emissions (87% or 56 Mt CO2eq) were due to enteric fermentation, while the remaining share was from CH4 (2 Mt CO2eq) and N2O (7 Mt CO2eq) from manure management. The weighted average emission factor for enteric fermentation per animal was 61 kg CH4/head/year (range: 31-83 kg CH4/head/year). Regionally, Sub-Saharan Africa, Northern Africa and West Asia accounted for 43, 12 and 4 Mt CO2eq, respectively, representing 94% of total camel-related emissions. The study projects that, assuming a linear growth of the population under BAU, camel emissions will rise to 75 Mt and 88 Mt CO2eq by 2030 and 2050 respectively, corresponding to a 15% and 30% increase from 2015 levels. Particularly in Sub-Saharan Africa, the increase is expected to be pronounced, with emissions forecasted to reach 52 and 63 Mt CO2eq by 2030 and 2050, respectively. A more moderate yet progressive increase is also expected in Northern Africa and West Asia, reaching 21 Mt CO2eq by 2050. Apart from Central Asia and Eastern Europe, where a slight uptick is predicted but will contribute less than 0.5% to the total, other regions are forecasted to see a decline in emissions from camels. These findings draw attention to the need for national and regional climate policies to consider the impact of the expanding camel populations on GHG emissions in countries of Sub-Saharan Africa, Northern Africa and West Asia, where the population is expected to drastically increase. Given the gaps in input data, further research and primary data collection are necessary to enhance the accuracy of emission estimates.

Keywords: agrifood systems, livestock production, greenhouse gas emissions, impact assessment, Global Livestock Environmental Assessment Model (GLEAM)

Transparent Horizons: IMEO's Methane Data Empowering Global Action

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The Global Methane Assessment estimates that agriculture accounts for about 40% of anthropogenic methane emissions, the majority of which are from livestock-related emissions. Without intervention, agricultural methane emissions are predicted to increase by about 30% between 2010 and 2050, largely driven by the projected rising demand for ruminant animal products (meat and milk), putting the goal of a 1.5 degree global temperature increase at risk. Ambitions on methane emissions reduction are growing, and open, reliable, measurement-based and actionable data is essential to track changes in emissions over time, and there is a high need for timely and transparent agricultural methane data. The ability of countries and companies to meet their targets relies on their abilities to take action at the speed and scale required, as well as being able to demonstrate progress towards these goals.

As a core implementing partner of the Global Methane Pledge, the UN Environment Programme's International Methane Emissions Observatory (IMEO) has been tasked with creating a sound scientific basis for methane emissions estimates and is providing reliable, public, policy-relevant data to facilitate actions to reduce methane emissions. IMEO is collecting and integrating diverse methane emissions data streams, including satellite remote sensing data, science studies, national inventories, and measurement-based industry reporting to establish a global, centralized public record of empirically verified methane emissions.

Here, we will show the progress of IMEO towards developing its global, public dataset of policy-relevant methane data, including plans to collect agricultural methane data at the country level. We will also open the discussion on how IMEO could collaborate with the agricultural science and greenhouse gas community.

Keywords: global methane data, enteric methane emission, national inventory

Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System

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The global agrifood system has been largely overlooked in the fight against climate change. Yet, greenhouse gas emissions from the agrifood system are so big that they alone could cause the world to miss the goal of keeping global average temperatures from rising above 1.5 centigrade compared to preindustrial levels. Greenhouse gas emissions from agrifood must be cut to net zero by 2050 to achieve this goal. The World Bank's recent flagship report 'Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System' offers the first comprehensive global strategic framework to mitigate the agrifood system's contributions to climate change, detailing affordable and readily available measures that can cut nearly a third of the world's planet heating emissions while ensuring global food security. These actions, which are urgently needed, offer three additional benefits: improving food supply reliability, strengthening the global food system's resilience to climate change, and safeguarding vulnerable populations. This practical guide outlines global actions and specific steps that countries at all income levels can take starting now, focusing on six key areas: investments, incentives, information, innovation, institutions, and inclusion. Calling for collaboration among governments, businesses, citizens, and international organizations, it maps a pathway to making agrifood a significant contributor to addressing climate change and healing the planet.

Keywords: Net zero emissions, collaboration

How much can we reduce emissions from livestock in the LAC region and what might it cost?

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Livestock in the LAC region (Latin America and the Caribbean) are a significant source of GHG emissions, and these emissions are not forecast to decrease significantly between now and 2050 in the BAU scenario. Without reductions in the AFOLU sector "it will be extremely difficult for LAC countries to achieve the NDCs and practically impossible for them to achieve global net-zero CO2 emissions" (Cárdenas and Orozco 2023, p11).

There is evidence that the LAC livestock sector could provide a large cost-effective reduction in emissions (we define cost-effective as <100USD/tCO2e). Much of the abatement could be achieved via productivity improving measures that would increase farm profit (i.e. CE <0USD/tCO2e). Once initiated, such measures are likely to be financially self-sustaining. However, there is chronic under-adoption of these measures, due to a range of barriers. Strategic investment could help to overcome these barriers. There are further measures that have a positive cost that is lower than the benefits of the avoided emissions (i.e. CE 0 to 100USD/tCO2e). These are efficient from a social perspective but will decrease farm profit. Incentives will likely be required to achieve widespread adoption of such measures.

In this paper we attempt to clarify the abatement potential in LAC, how it could be achieved and what it might cost. We do this firstly by undertaking a critical review of existing estimates of mitigation in the LAC region and identifying common messages (and inconsistencies). We also highlight some issues, for example limitations in the way in which additionality is dealt with. Secondly, we undertake some case studies in which we calculate the abatement potential and cost-effectiveness of packages of measures and discuss how barriers to uptake may be addressed.

Keywords: mitigation, cost-effectiveness, cattle, Latin America

GHG Baseline Assessment for Emission Reduction in Victoria, Laguna Rice Farming

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Rice farming is a primary agricultural activity in Victoria, Laguna, with notable contributions to greenhouse gas (ghg) emissions, particularly methane and nitrous oxide. In 2019, rice sector in the Philippines emitted 43 million metric tonnes of CO2e accounting to 18.72% of the country's total emissions. This study establishes baseline emissions from conventional rice farming in Victoria, quantifying an annual average of 2.29 kg CO2e per kg of rice grain (2.24 kg CO2e/kg for the dry season and 2.43 kg CO2e/kg for the wet season) based on practices that incorporate rice straw into the fields.

This baseline data is essential for the comparison of ghg reduction potential best practices which can be applied in the country. One research study in collaboration with rice straw is looking at a potential reduction of using removing rice straw from the field. Based on IPCC methodology, potential ghg reduction for rice removal is 33% underscoring the significant impact of rice straw management on GHG emissions.

The project partner, Straw Innovation—a UK-based agriventure company—is advocating for low-carbon emission farming through the removal of rice straw from fields and its possible conversion into bioenergy and biofertilizers. This practice not only reduces GHG emissions but also adds value to rice straw by redirecting it for alternative uses, thereby further reducing emissions.

The study assesses the current rice farming practices in Victoria, Laguna, and the potential of transitioning to low-carbon emission farming. Ongoing soil flux and GHG emission measurements in the rice cropping area will provide deeper insights into the impact of straw removal during rice cultivation. By comparing conventional farming with straw removal methods, we demonstrate the substantial reduction in emissions achievable through this innovative approach. Our findings offer practical recommendations for farmers and policymakers to adopt sustainable practices and contribute to climate change mitigation efforts.

Keywords: greenhouse gas emissions, low carbon farming, rice straw management, sustainable agriculture, climate change mitigation

The impact of functional groups of forage species on the grassland GHG exchange

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The increasing amount of greenhouse gases (GHGs, carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O) in the atmosphere is the main cause of global warming. The agricultural sector in Finland produces 13% of total GHG emissions and it is the largest source of anthropogenic N_2O emissions. However, agricultural lands also have the potential to act as a sink for atmospheric carbon. About a third of Finland's arable land is under grass production, so the climate-smart development of grass cultivation is a significant part of Finland's carbon neutrality goal in 2035.

Cultivation of deep-rooted perennial grasses, such as tall fescue (*Festuca arundinacea. Schreb*), has been reported to increase the carbon stocks in mineral agricultural soils. Introducing N_2-fixing perennial legumes, such as red clover (*Trifolium pratense L.*), into agricultural grasslands may reduce the need of synthetic mineral N-fertilizers and mitigate N_2O fluxes.

In this research, we measured GHG exchange of a grassland cultivated with these two functional groups. The research was conducted in a 6.3 ha agricultural field on a mineral soil, near Maaninka, eastern Finland. During a two-year study period the GHG exchange during growing season was measured weekly from intensive plots using the closed-static-chamber technique, while during winter months with the snow gradient method. We also measured plant, soil, and environmental variables from these plots to help explain the GHG exchange patterns. This presentation describes the GHG exchange trends as affected by different functional groups of forage species during the two years.

Key words: climate smart agriculture, legumes, nitrous oxide, carbon dioxide

Creating a tool to predict manure methane emissions for farmers and policy makers

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Greenhouse gas emissions from manure management are highly varied throughout the year. Research has shown that methane emissions in the UK from cattle slurry in summer (July to September) can be 61 times greater than the same volume of slurry stored in winter (December to February) [https://doi.org/10.2134/jeq2015.12.0618]. Additionally, the volume of slurry stored throughout the year changes due to animals being out to pasture in summer months and slurry being applied to crops or grassland (in which case methane emissions drastically reduce). However, greenhouse gas inventories, and most farm carbon tools calculate emissions from manure based on the total volume of slurry generated in a year multiplied by a factor representative of the average-yearly temperatures, overlooking the seasonality of emissions and manure generation, as well as the impact of climate change. Encouraging farmers to adapt their practices to minimise the volume of slurry stored over hot periods or apply mitigation methods over high temperature and slurry volume periods has the potential to drastically reduce greenhouse emissions from manure management with little economic cost and minimal impact on production.

In this project we aim to develop a model to carefully quantify air-temperature effects on stored slurry methane emissions at daily resolution. Since experiments on slurry methane emissions typically use slurry temperature as the control variable, we first present a model of slurry methane emissions as a function of slurry temperature. We then use a thermodynamic model to estimate slurry temperatures based on air temperatures. Both models are parameterised independently using existing experimental data in the literature and validated together using a separate experiment.

We will present two use-cases for the model. The first calculates methane emissions at a national scale by using maps of cattle distributions, and spatial future and historic temperatures from the UK. We present results on how methane emissions from manure management has been affected by climate change and offer a method for calculating the emissions factor for manure methane while considering the local temperature of where manure is stored in the UK. The second use-case implements the model as a farm decision-support tool by integrating it with local weather forecasts and a web interface for entering farm parameters (location, milk yields, number of animals) and management decisions (when are the cows brought inside, when was the slurry storage last emptied). The web interface then runs the model and predicts slurry methane emissions to help farmers make decisions to reduce emissions, see Figure below.

Finally we argue that efforts should be made to ensure models that are developed to estimate agricultural emissions at national scale are made available to farmers to both encourage behaviour change, and to more accurately capture management decisions in national inventories.

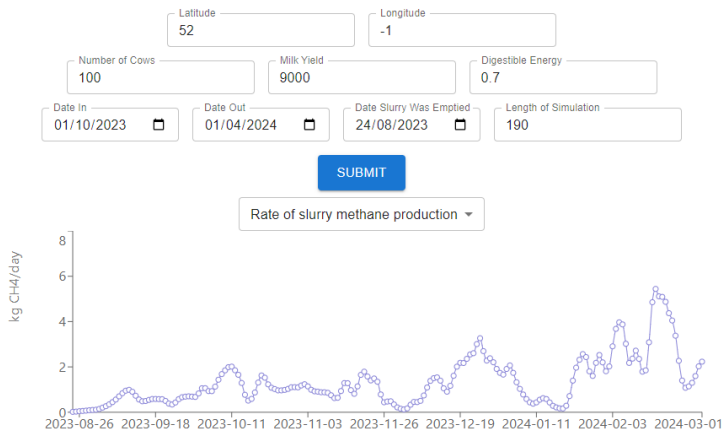

Fig: Example input/output for the web-based decision support tool

Keywords: methane emissions, manure management, modelling, decision support tool, impact study

Creating enabling environment for agricultural mitigation in South Africa

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The agricultural sector can have a meaningful contribution to climate change mitigation in South Africa and throughout the world. The mammoth task of attaining the net zero by 2050 needs to be undertaken by all sectors and countries regardless of contribution. In this study, we explored the elements that are needed to promote and ensure that South African agricultural sector is ready to mainstream mitigation activities. Our study reviewed literature to understand the enablers in the current state and conducted key informant interviews with experts to establish the requirements for optimum conditions for agricultural mitigation. The informants were sourced from academia, research institutions, climate policy makers, government officials, agricultural producers, carbon management consultancy, farmers unions and farmers associations. The results of the study show that South Africa's main barrier is the absence of clear policies that are geared towards climate change mitigation because the priority in the country had always been for advancing climate change adaptation from the agricultural perspective. There is also no interconnection between the stakeholders that could form a required ecosystem for mitigation in the agricultural sector. The absence of extensive national dataset of greenhouse gas emissions (GHG) fluxes across all the major agricultural commodities is also perceived as a constraint. The latter calls for special efforts by all the role players to initiate GHG research along the agricultural value chain of major commodities. Investment in carbon financing mechanisms that supports agricultural activities is one of the enablers that were identified. For South Africa to attain the integral involvement of the agriculture in climate mitigation, there needs to be improvement in institutional arrangement and alignment, formations of new institutions and governance mechanisms.

Keywords: carbon financing, GHG fluxes measurement and research, policy development

Beyond the 'new tradition' in developing bottom-up policy: A pathway to maximise the impact of social and behavioural science in the transformation of zero carbon policy to mitigation actions

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Statement of the problem: EU and national climate, environment and agricultural policies all stress the imperative of achieving a zero-carbon economy by 2050. In Ireland, reducing emissions from agriculture is a key element of the national greenhouse gas (GHG) reduction strategy as the sector accounts for 38.4% of national GHG emissions compared to EU average of 10%. A target reduction of 25%, compared to 2018, is established in the national Climate Action Plan. Achieving this target will require the widespread adoption of various mitigation measures, strategies, and practices at the farm level, while ensuring the competitiveness of Ireland's agri-food sector. Despite the presence of scientific advancements, technological solutions, and financial support for their adoption, i.e. the traditional support structure, persistent low and inconsistent uptake of certain mitigation measures poses a significant challenge to meeting the reduction targets.

There is a lot of behavioural research on factor influencing the adoption or non-adoption of new technologies or knowledge by farmers. Key behavioural factors include economic, environmental, background/business, policy/regulation, and social and cultural. This paper identifies behavioural factors considered in past studies explaining adoption of GHG mitigation measures in pasture-based systems.

In deploying this approach, it is important to note that the ontology, epistemology, and research approaches employed in behavioural studies may result in explanations that are predominantly technological, technical, economic, and structural in nature. Failure to consider the social and cultural aspects, particularly those related to decision-making could hinder the effectiveness of promoting certain mitigation measures/actions, e.g. those related to land use, land use change, and farm biodiversity.

Objective: This study implements a systematic review of the academic literature to identify social and cultural considerations in behavioural studies explaining adoption of GHG mitigation measures in pasture-based system. This illustrates that to what extent behavioural studies used to inform policies are coherent and inclusive, and to identify were social and behavioural science can contribute to the of policy to action.

Methods: A systematic review of academic literature identifies literature that seeks to understand farmers' behaviours regarding the adoption of mitigation practices in pasture-based farming systems was undertaken. Three questions were addressed: 1) Are the social, psychological, and cultural considerations associated with adoption mitigation practices, considered within this body of work? 3) What ontology, epistemology, and approaches have been applied to explore/explain the factors affecting farmer decision-making?; 3) What behaviour change policy or technical recommendations have been made?

Key findings and policy implications: The findings of this study are used to design a pathway to integrate social and behavioural science into research and innovation agendas that seek to ensure effective, cohesive and inclusive policy and extension programmes relating to climate change. To illustrate the application of a pathway, the role of social and behavioural science, as an integral part of the Teagasc Climate Centre in transforming research into policy and practice is presented. Ultimately, it provides an example of how social and behavioural science can contribute to achieving national and EU climate targets and effecting farm-level behavioural change.

Keywords: zero carbon policy, social and cultural considerations, adoption of mitigation measures, bottom-up approach, pasture-based farming system

Incorporation of Low-Methane Sheep Genetics into the National Greenhouse Gas Inventory

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Research into the potential of breeding for lowered enteric methane-emissions in sheep has been underway in New Zealand since 2007. This work has established that there is variability in the quantity of methane emitted per unt of feed eaten (lower methane yield), and that this variability has a genetic component with an estimated heritability of 0.29 ± 0.05. So far there is no evidence that important production traits, such as growth rates, wool production and disease resistance, are compromised in the low-emitting line.

A major advantage of reducing methane emissions via genetic selection is that improvement can be continuous and once introduced, the improvements don't require continuous intervention on a day-to-day basis by farmers. This is vital for pastoral grazing systems where opportunities to interact frequently with animals is limited, meaning there are fewer options to reduce emissions. For the gains from genetic improvement to be recognised in New Zealand's national and international targets, the impact must be quantified in the National Greenhouse Gas Inventory. Any change to National Greenhouse Gas Inventories should improve the quality of the Inventory, therefore, the scientific basis for the inclusion should be robust, and the implementation transparent.

Gene flow modelling is required to predict the prevalence of the low-emissions trait in a population, and the subsequent impact on the methane yield of that population. The gene flow model needs to estimate a time series of the average genetic merit of rams used to determine the impact mating decisions have on gross methane emissions at any particular point in time. This involves tracking the number of "expressions" of genetic merit observed in the rams and their descendants and then calculating the impact of changes in ram merit with respect to enteric methane emissions over time. Genetic and sales data can be used to track the breeding value of rams in the New Zealand flock.

Several different pieces of information are needed to calculate the absolute methane reductions within the national flock. These include:

- The average merit of rams purchased each year, and the proportion of rams reused in subsequent years.
- The expected genetic trend for methane reductions in future years.
- The size and structure of the national flock, including lamb weaning rates (lamb/ewe), proportion of breeding ewes mated as hoggets, ewe survival and the proportion of ewes mated to terminal rams.

The ongoing challenges of adopting a complex mitigation like this into the national inventory will be detailed further in the presentation.

Keywords: greenhouse gas inventory, agricultural mitigations, low-methane sheep genetics, Agricultural emissions

Assessing the impact of conservation agriculture and biochar on greenhouse gas emissions in northern Uganda

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Conservation agriculture (CA) and application of biochar (BC) are important components of climate smart agriculture. However, little is known about their effect on emissions of nitrous oxide (N_2O) and methane (CH_4), especially in sub-Saharan Africa (SSA) were studies on GHG are generally few, compared to other regions. With a limited number of studies, there is a need for further investigations as this region has considerable impacts on the global greenhouse gas budget. We carried out an experiment to investigate the effect of maize-pigeon pea rotations, reduced tillage, and biochar application on GHG emissions at an in-depth experimental trial in Gulu, Northern Uganda. Reduced tillage involves the use of planting basins dug by hand, using a hoe. Uganda has a bimodal rainfall system; therefore, the samples were collected from May 2023 to September 2023 during the first season, and from September 2023 to January 2024 during the second season. Pigeon pea (*Cajanus cajan* L. Mill sp.) was grown in the first season and rotated with maize (*Zea mays* L.) in the second season. The treatments are as follows: (1) reduced tillage + biochar + maize-pigeon pea rotations (CA+BC), (2) reduced tillage + maize-pigeon pea rotations (CA), (3) conventional tillage + maize-pigeon pea rotations (Convent+PP), and (4) conventional tillage + maize monocrop (Convent+MM). In accordance with common smallholder practice, none of the treatments received inorganic fertilizer. GHG samples were collected after every 2 weeks, both between rows and within planting basins, using the static chamber method. Simultaneously, soil water content was being measured using TDR moisture sensors with the data being continuously logged, while also soil samples were taken, stored on ice, and extracted with 2M KCl to determine soil ammonium and nitrate concentrations. The GHG samples were analysed on a gas chromatograph (GC; model 7890A, Agilent, Santa Clara, CA, USA) connected to an auto-sampler (GC-Pal, CTC, Switzerland), while flow injection analysis (FIA star 5020, Tecator, Sweden) was used to analyse mineral N, at Norwegian University of Life Sciences. NH^+_4-N was significantly more than NO_3-N, for both seasons, however, there were no treatment differences on mineral N. The fluxes ranged from 0 – 40 µg N_2O-N m^{-2} h^{-1} in the basins, and from 0 – 70 µg N_2O-N m^{-2} h^{-1} in the inter-rows. N_2O-N fluxes were positively correlated with water filled pore spaces (WFPS) and mineral N. Cumulative N_2O-N emissions for 259 days ranged from 0.6 – 1.11 kg N_2O-N ha^{-1}. Surprisingly, we observe CH_4-C emission rather than uptake, possibly related to extensive termite activity; and the emissions ranged from 2.01 – 3.93 kg CH_4-C ha^{-1} for 259 days.

Key words: conservation agriculture, biochar, GHG, low-input systems

Climate protection targets and emissions projections for agriculture and land use in Germany

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Projection reports are intended to provide information about the future expected developments in greenhouse gas emissions and thus supplement the reporting of emissions for previous years. This contribution examines the increasing importance of projection reports in German climate mitigation policy for checking whether targets have been achieved and assessing the effects of decided and planned climate protection measures.

With the Federal Climate Protection Act, in 2019 sectoral climate protection targets were defined, including agriculture. In 2021, the targets were raised slightly in response to a Federal Constitutional Court ruling on insufficient intergenerational equity in climate protection policy. In addition, target values were set for the land use sector. In April 2024, a further change to the Federal Climate Protection Act was passed. In the future, target achievement will be checked across sectors based on the expected development of total emissions. The basis for this annual assessment shall be the projection reports, which therefore acquire central importance. The target contributions of the individual sectors should continue to be documented, but the binding nature of target achievement and the obligation to launch sectoral emergency programmes if targets are missed will be lifted.

The 2023 projection report (Harthan et al. 2023) presents a scenario with existing measures (WEM), which shows decided measures and their effects, and a scenario with additional measures (WAM), which contains additional, specifically planned but not yet decided measures. The basis for this is the 2030 climate protection programme and the measures and funding schemes based on it. In the WEM, the targets for the agricultural sector are over-fulfilled. Until 2030, accumulated credits amount to 20 million tonnes of CO_2eq. In the WAM, assuming that further measures are successfully implemented, the over-fulfillment even amounts to 40 million t CO_2eq.

In the 2021 projection report, however, it was assumed that the target would be missed by 2030. The reason for the large deviations in the estimates in the last two projection reports is the introduction of a new, improved methodology for calculating direct nitrous oxide emissions based on measurement data from Germany. As a result, the reported emissions from agriculture fall by around 5 million tonnes of CO_2eq. per year is lower than with the old calculation method. Further, livestock numbers and mineral N input have decreased more than expected, contributing to lower emissions.

In the land use sector (land use, land use change and forestry - LULUCF), the goals of the Climate Protection Act are projected not to be achieved in both scenarios, despite the comparatively optimistic assumptions regarding peatland protection. The assumed decline in peat mining to zero by 2040 also contributes to the projected development.

In August 2023, the Expert Council for Climate Issues called for systematic monitoring of implementation and an impact assessment of the emissions reductions actually achieved in a statement on the 2023 climate protection programme. In the future, the ex-ante assessment of climate protection policy through projection reports must be supported by the ex-post evaluation of climate protection measures. This contribution is intended to be updated based on the 2024 projection report, which will be published soon, and to analyze the influence of trends of activity data, the effects of mitigation measures and methodological changes on emissions.

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Keywords: national emission reduction targets, projections, mitigation measures, agriculture, land use

Low -dose acidification: Farm-scale evaluation of a promising methane mitigation strategy

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Manure is a significant source of methane (CH4) emissions from dairy and pig production with liquid manure management. Acidification with sulfuric acid (H2SO4) to prevent ammonia losses is known to also reduce CH4 emissions dramatically during storage, but at 6-12 kg H2SO4 m-3 the cost is significant. A recent study (Ma et al., 2022) demonstrated that a much lower rate, 2 kg H2SO4 m-3, may still achieve a >50% reduction of CH4 emission from stored liquid manure (slurry), and a preliminary economic assessment indicated a cost of <50 € ton-1 CO2e depending on the need for mixing during storage when fresh manure from barns is added. Here, we present the first results from a full-scale evaluation of low-dose acidification of slurry in storage tanks on pig and cattle farms across western Denmark. The objective of the project is to provide a basis for deciding the viability of low-dose slurry acidification for CH4 mitigation on livestock farms. For the first storage period (2023-2024), eight tent-covered tanks with pig slurry and eight tanks with cattle slurry were used, two of which were left without acidification, while the other six tanks were acidified corresponding to a rate of 2 kg H2SO4 m-3 when filled, but employing three different mixing strategies (1x, 3x or monthly). Acidification of pig slurry took place in early July, and again in early autumn after slurry application to winter crops, whereas cattle slurry was not acidified until early autumn since slurry is applied to grassland during summer. The focus in the first year was on the efficiency of acidification, and on three occasions (October, December, February) 1-liter slurry samples were collected at 1 m depth intervals and analysed for selected properties, and for CH4 production rates an in-vitro assay was used (Petersen et al., 2024). The results confirm that CH4 production in the slurry is effectively suppressed by low-dose acidification during long-term storage. However, in some cases significant CH4 production rates were measured near the inlet where fresh slurry from the barn is introduced, suggesting some stratification at the time of sampling. In the second storage period (2024-2025) the CH4 emissions from selected tanks are quantified using a trace gas-pulse method to quantify CH4 mitigation by low-dose acidification at full scale. Concurrent sampling and analysis of slurry takes place, as in the first storage period. The cost-effectiveness of different acidification strategies will be analysed for commercial farms with pig and dairy production. This analysis will consider time of acidification, mixing frequency, and a new technology for in-line acidification during transfer from barn to storage tank.

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Keywords: liquid manure storage, methane emission, acidification, manure properties, cost-efficiency

Changes in organic carbon stocks of German agricultural soils in the past decade

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The German Agricultural Soil Inventory (BZE-LW) has been first conducted between 2011 and 2018 with the aim of establishing a comprehensive baseline of SOC stocks that could be used for higher Tier approaches in reporting soil organic carbon (SOC) stock changes in agricultural soils. SOC stocks down to 1m depth were estimated for a total of 3104 sampling points in a 8x8 km grid. Meanwhile, a resampling of this national grid has started and first results can be evaluated. Here, the trend in SOC stocks of the first approximately 500 sites will be presented and discussed. The results will also be used to build a statistical model to advance the methodology of SOC change reporting in the framework of the national greenhouse gas inventory report as a trajectory towards a fully process based modelling approach. The German strategy towards a Tier 3 approach for SOC stocks in agricultural soils will be outlined.

Keywords: LULUCF, National Inventory Reporting, carbon sequestration, BZE

Marginal abatement costs of combining GHG mitigation technologies in NZ dairy systems

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New Zealand's agriculture sector contributes about 50% of the nation's gross greenhouse gas (GHG) emissions. An overwhelming majority of agricultural emissions, specifically 90%, can be directly attributed to ruminant livestock, including dairy cattle. Reducing these biological GHG emissions from New Zealand's dairy system through various mitigation options has been a primary research focus. The heterogeneous nature of farm systems affects the effectiveness of GHG mitigation options, which present unique challenges and opportunities for reducing GHG emissions.

The effectiveness of individual GHG emissions mitigation technologies can vary when they are combined in 'bundles' of multiple technologies. Thus, cost-effectiveness varies across farming systems and depends on the nature of the technology bundle. It is essential to gauge these implications to promote the adoption of mitigation technologies. Therefore, we derived Marginal Abatement Costs (MAC) of varying technology bundles to compare the cost-effectiveness of GHG mitigation technologies. TheMAC provides valuable information for policy analysis and decision-making. Marginal abatement costs of existing studies often do not consider the interactions among mitigation technologies.

This research is a part of the Climate Neutral Farms (ClieNFarms) initiative and was based on the Southern Demonstration and Research Farm (SDRF) of the Southern Dairy Hub (SDH), near Invercargill. The four proposed farmlets at the SDRF, differing in feeding and management, were used as case-study farms. MACs were derived from scenario modelling of the SDRF farmlets with combinations of technology options to reduce GHG emissions, which could be easily upscaled to a commercial farm. Technologies simulated included high animal breeding worth, reduced stocking rate, feed type substitution, forestry and alternative cropping, and fertiliser management.

In our study, interaction effects between technologies enhanced reduced marginal abatement potential and the overall GHG abatement potential compared to the individual mitigation technologies. However, the GHG offsetting potential of some technology combinations is limited.

Keywords: abatement cost, climate, dairy, policy, GHG

Using GHG emission metrics to inform mitigation choices: linking science with policy goals

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Agriculture, in particular livestock systems, produce a range of greenhouse gases (GHGs). A variety of interventions exist that could reduce emissions, but they generally reduce emissions of different gases by different amounts and at different costs. In some cases, efforts to reduce emissions of one gas could even result in increased emissions of another gas. GHG emission metrics can help direct efforts at those interventions with the largest benefit for the climate at the least cost. In addition, GHG emission metrics can give a sense of what overall abatement effort in livestock systems could be considered fair or proportionate compared to efforts to reduce emissions in other sectors. However, a variety of GHG emission metrics exist (e.g. GWP100, GWP20, GTP, GWP*) and different metrics can paint a very different picture about what abatement options are the most beneficial for the climate, and which ones are proportionate compared to abatement in other sectors.

We illustrate those differences by applying a variety of GHG emission metrics (a) to existing net-zero or other quantitative net emission targets, (b) to determine the most cost-effective abatement options with the largest climate benefit, and (c) to illustrate what mitigation efforts might be considered proportionate to efforts in other sectors. We show that, consistent with conclusions by the IPCC 6th Assessment Report, changing metrics while keeping the numerical emission target unchanged alters the climate outcome and effort required to meet the target. Metrics also give different answers when applied to determine the most cost-effective mitigation approach, with this difference also depending on the duration of the intervention (i.e. one-off or a sustained change) and the time horizon over which cost effectiveness is considered. All metrics can be used to illustrate what abatement efforts might be considered proportionate across sectors, but care needs to be taken how those metrics are applied.

Overall, GHG emission metrics can make an important contribution to inform abatement choices in complex multi-gas systems such as livestock production, but the choice of the most appropriate GHG emission metric and how the metric is used depend entirely on the policy goal that is assumed for mitigation and the degree to which the chosen metric is consistent with that policy goal.

Keywords: GHG emission metrics, GWP, trade-offs, science-policy alignment, methane

Soybean by-products reduce enteric methane emissions from dairy heifers

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By-products from the cropping industry such as expellers or meals are used as protein sources. Changing from meal to expellers can modify the energy source of the diet due to higher lipids content compared with starch, thus reducing CH_4 and the use of grains. However, limited information exists to conclude about the impact of this feeding strategy. The aims of this study were to quantify the enteric methane mitigation potential and the replacement of grains for cattle supplementation. For this, two dietary treatments were offered once a day to 12 one-year-old Holstein heifers (240±11 kg LW). Diets were formulated to be isoproteic (150 g CP/kg DM) and isoenergetic (2.5 Mcal ME/kg DM), varying in the concentration of lipids and starch. Diets of both treatments had 60% (dry matter basis) whole-plant sorghum silage and 40% of concentrate. For the control diet (**CTRL**), concentrate had maize grain:soybean meal (40:60), whereas the alternative diet (**EXP**) had maize grain:soybean expeller (20:80). Treatments were tested in a crossover design, with two measurement periods. Heifers were transferred to individual pens at the methane measurement laboratory shed. Each period consisted of 14 days of acclimatization followed by 3 days of measurement. Dry matter intake (DMI) was measured by gravimetric difference of the offered and refused feed during the last 3 days of acclimatization and during the measurement days on chambers. Heifers entered individually to one of the two respiration chambers to measure enteric CH_4 emissions and DMI, continuing with the same feeding and pen cleaning routine. Heifers remained for 3 days inside the chambers and once the measurement finished, they were gradually fed the opposite dietary treatment for 14 days followed by the second measurement period. Chemical composition was determined on the offered and refused feeds and heifers live weigh was recorded every 14 days with an electronic scale to monitor weight change and adjust the amount of feed offered. R Studio program with CrossCarry package and analysis of variance for crossover design were used for statistic analysis. No differences were observed on DMI (6.97 vs. 7.31 kg/d, 0.212 SEM, P=0.193), ME intake (17.6 vs. 17.8 Mcal/d, 0.462 SEM, P=0.454), and LW (285 vs. 282 kg, 3.86 SEM, P=0.82) of heifers fed EXP vs. CTRL diets, respectively. Heifers fed EXP had lower (P<0.0001) CH_4 production (159 vs. 191 g CH_4/day, 5.21 SEM), CH_4 intensity (0.559 vs. 0.675 g CH_4/kg LW, 0.014 SEM), and estimated *Ym* (6.86 vs. 8.35 %, 0.217 SEM) than those fed the CTRL diet. These results could be explained by the higher intake of lipids (0.412 vs. 0.188 g EE/day, 0.007 SEM, P<0.0001) and lower intake of starch (0.702 vs. 1.049 g starch/day, 0.055 SEM, P<0.0001) of heifers fed EXP than CTRL diet. By replacing soybean meal by expeller in backgrounding diets, energy loss as enteric CH_4 was reduced by 18%, together with a decrease of the dependence on maize grain of 40%. Human non-edible food such as by-products from the cropping industry can reduce methane emissions without compromising food supply for human consumption.

Keywords: greenhouse gas mitigation, non-edible human food, beef backgrounding

Development of sustainability indexes in plant and animal breeding

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There are several genetic selection strategies that can be incorporated into breeding programs to target a reduction in GHG emissions and provide a mitigation strategy with only very modest additional cost, or labour expense to the farmer. Additionally, genetic selection offers a permanent and cumulative solution to reduce GHG emissions and improve sustainability, with the reduction in emissions continually building on the previous progress. This can be achieved by targeting genetic progress in a specific trait (i.e. methane) or by building selection indexes that balance economic gain and environmental impact for more conventional traits, or both. Various countries have initiated efforts to incorporate emissions-related traits into their national selection indexes. However, in most cases, incorporating a direct methane breeding value will not be possible for an extended period of time. An alternative approach is to optimally select current index traits to reduce emissions. Methodology has been developed that quantifies the independent impact of current trait on emissions in livestock. The non-methane traits commonly identified as having an independent effect on system-wide gross emissions include traits related to production, longevity, fertility and feed efficiency. Livestock methodology has since been expanded to incorporate the multifactorial aspects of plant sustainability considering a trait's independent impact on externalities such as acidification and eutrophication. While each industry has developed breeding programs with a focus on broader sustainability goals, the strategies for reducing emissions vary due to the specific objectives and limitations of each agriculture system. These initiatives highlight diverse approaches to breeding for reduced methane emissions, ranging from specific methane breeding values to broader sustainability indexes. Often 40 - 50% of the maximum possible reductions in emissions may be achieved with only modest sacrifice of economic gain due to ellipse response properties of selection indexes. Therefore, the optimal selection scenario includes the implementation of a direct methane trait, in combination with additional emphasis being applied to traits with environmental impact. However, emissions coefficients may be immediately implemented in the short term as a tool that farmers can use for industry application to reduce emissions while maintaining profit, until a reliable methane trait is available. Overall, current breeding strategies demonstrate a commitment to sustainability and environmental responsibility within the dairy industry. Motivation for use of these sustainability indexes is strengthening in high income countries. This motivation could be much higher if a clear pathway to developing auditable, transparent and scientifically robust ways of recognising emissions changes due to genetic selection to support both national policy setting, and supply agreements with processors.

Keywords: genetic selection, animal breeding, selection indexes, plant breeding

Gender-Just Mitigation in the Agri-food systems Sector: Potential and Pitfalls

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Climate change mitigation in the agri-food systems sector is largely focused on practices and approaches for which significant gains can be made in sequestering carbon or reducing greenhouse gas (GHG) emissions. Most emissions reduction and carbon sequestration strategies focus on livestock and rice systems, crop nutrient management and land-based and soil health approaches, such as agroforestry and land restoration. The need to address mitigation along entire food value chains, for example, through lower-emissions transportation of agricultural inputs and food, or through food loss and waste interventions is also increasingly accepted, but a strategic assessment on high-potential interventions is lacking. And yet more recently interventions in the food environment, for example, through integration or strengthening of environmental considerations in food based dietary guidelines or incentives to dismantle food deserts are being considered.

Importantly, up to now, mitigation action has been largely gender-blind. As mitigation programs are rolled out, there is therefore considerable risk that women will not only be excluded, but that such programs, moreover, exacerbate gender inequalities in agri-food systems. This is worrisome because women have important contributions to make to mitigation: they are often more likely to manage livestock and have outsized roles in food storage and processing as well as in decision on food purchases and preparation. If mitigation in agri-food systems does not consider or consult with women, they might lose wages, incomes and agency in agri-food systems. Moreover, the promotion of agroecological approaches that support carbon storage often require proportionally more labor from women farmers as compared to men farmers. At the same time, women farmers seldom hold land titles and thus fail to benefit from carbon market payments linked to carbon sequestration, even if they provide most of the labor supporting these systems. While solar irrigation is an important agricultural mitigation option that is rapidly gaining traction, indiscriminate deployment of solar irrigation systems can affect drinking water access, which affects women disproportionately due to their roles as collectors of drinking water.

This review will introduce a framework that identifies the key gendered linkages to mitigation in agri-food systems as well as a systematic review to identify areas where women may be disproportionately affected by mitigation efforts, e.g. in terms of gender gaps in labor burden, income or nutrition. The review will also elaborate the key constraints to women's ability to participate in and benefit from mitigation actions in food systems, explore approaches to increasing gender equality in mitigation actions and compile a set of promising approaches or best practices based on the review.

Keywords: gender, mitigation, agri-food systems

Sustainable bioenergy for rice growing communities in the Philippines as pathway to the UN Sustainable Development Goals

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Rice is the main agricultural crop in Asia and is central to the food security of many regions. Every tonne of rice produces about 1 tonne of straw cumulating to an estimated 550 Mt across Asia. The current uses for rice straw are limited, and about 60-80% are disposed unsustainably, with significant environmental and health impacts.

This presentation introduces the sustainability assessment of rice straw bioenergy and share the experiences of an operating 1,000 m_3 rice straw biogas facility in Laguna, Philippines. In the Philippines rice is grown in crop cycles of 5-6 months, and straw burning, or incorporation are the most common ways to prepare the fields for the next crop. As alternative to the common rice straw management practices, potential rice straw bioenergy business models were developed in consultation with local communities [1], including biogas production for electricity generation, pumping of irrigation water and domestic cooking. An integrated sustainability assessment investigated how bioenergy integration can create sustainability benefits for local rice growers in the region of the pilot plant.

The environmental lifecycle assessment of the study identified the performance of the biogas system and compared it to current straw management practices [2]. Focus was given to climate change and temporal emission impact. The timeframe of the biogenic emission fluxes of rice production is particularly relevant as the sequestered CO_2 during plant growth is partly released as methane and CO_2, depending on the straw management practices. GWP100 is the main metric to inform policy, but it does not capture the impact of different forcers, like methane, a short-term forcer.

Straw burning had the highest net emission impact. However, straw incorporation has the highest short-term temperature impact, exceeding burning by ~25%. The biogas system provided significant emission reduction in the short and long term of ~70%, in particular when it replaces fossil fuel-based energy carrier, supporting SDGs 7 and 13.

The wider sustainability mapping used the Supergen Bioenergy Hub's Bioeconomy Sustainability Indicator Model (BSIM) [3] assessing wider benefits of the whole rice value chain and how the bioenergy integration can add value and benefits to local rice growing communities, including social and economic impacts. The results showed that the bioenergy from rice straw can create co-benefits and positive non-market values supporting SDGs 2, 3, 8, 9, 11, 12 and 17.

Transitioning to sustainable rice management practices is fundamental to developing a sustainable and prosperous rice economy in Southeast Asia. Engaging with farmers and relevant stakeholders and offering opportunities for co-design and participation enables the transition. Supporting farmers this way can lead rice production to achieve multiple United Nations Sustainable Development Goals beyond SDG 7 (energy) and 13 (climate).

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Keywords: rice straw, bioenergy, sustainability mapping, lifecycle assessement, Philippines

Capacity building for national greenhouse gas inventories: quantification of Tier 2 emission factors in rice, cattle, and poultry systems in Colombia

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In Colombia, the agricultural sector is the main source of GHG emissions in the country. According to the latest National GHG Inventory (2022), the country's net emissions are equivalent to 302,974 Gg CO2eq, where the Agriculture, Forestry and Other Land Use (AFOLU) sector accounts for 59% of emissions (179,623 Gg CO2eq). Within this sector, the main source of emissions is associated with land use change, particularly deforestation (conversion of forest land to cropland and pasture), amounting to 109,288 GgCO2 or 73% of the sector's emissions. In addition, enteric fermentation (from livestock) corresponds to 14% of the country's total emissions, followed by methane emissions from water management in rice cultivation, and nitrous oxide emissions associated with the use of nitrogen fertilizers. Currently, Colombia's GHG inventory is based on a Tier 1 approach, which is why national authorities are considering quantifying emissions at Tier 2 level as part of their improvement options.

Emissions of N_2O and CH_4 from manure management in cattle farming and CH_4 emissions from rice cropping systems are considerably higher in the sector, given the country's cultivated area. In contrast, emissions from poultry manure management are not significant at the national level, however, the lack of information in the country has hindered quantifying its mitigation potential not only at the system level but also its potential to include poultry manure management as a fertilization strategy in cropping systems.

Improving the national greenhouse gas (GHG) emissions inventory is a key first step toward understanding and managing national emissions and mitigation strategies. The quantification protocol proposed and adopted by environmental authorities involved the closed static chamber technique, which allows quantifying GHG emissions per unit of C and N input. To generate country/regional-specific emission factors, data collection trials were implemented on productive farms in two main producing regions of Colombia, Valle del Cauca for poultry and Casanare for cattle and rice. To ensure the representativeness of the collected data, multicriteria spatial analyses were conducted to define the most representative areas in the region in terms of soil-climatic, landscape, and productive conditions.

The Tier 2 emission factors quantified are considerably lower than the default emission factors, resulting in inventory adjustments with reductions of up to 75%. The obtained values are being included in the national GHG inventories, to subsequently address mitigation strategies promoted by national authorities.

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Keywords: climate change mitigation, Tier 2, poultry, cattle, rice

Accelerating change: combining biological proxies to reduce biogenic methane emissions in ruminants

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In New Zealand, 53% of greenhouse gases are derived from agriculture, with 80% of this in the form of enteric methane from grazing livestock. Under GWP_{100}, current estimates are that livestock emissions will need to be reduced by 10% by 2030 and 24-47% by 2050. Breeding has been shown to be a sustainable strategy for the reduction of enteric methane emissions and to date is the only technology to be employed nationwide. Barriers to rapid acceleration of breeding programs have been the lack of rapid phenotypes to derive sufficient selection pressure. Here, we describe a suite of biological proxies for methane emissions including portable accumulation chambers (PAC), host genome and rumen microbial profiles from a single swab, volatile fatty acids, and milk and meat fatty acids. More than 4000 RMC profiles were generated from rumen samples collected on sheep immediately after being measured through PAC using restriction enzyme-reduced representational sequencing (RE-RRS). Accuracy of prediction was improved 2-fold by combining host genotype and RMC. We have generated methane predictions from a range of sources and estimated correlations between the sources of information. Using a subset of 600 lactating ewes, The traits methane (CH_4) and carbon dioxide (CO_2) emissions (grams per day), as well as the ratio $CH_4/(CO_2 + CH_4)$ (CH_4Ratio), were predicted from the RMC profiles, genotype data and fatty acid data using both PCA based and conventional GBLUP linear mixed models. Our results show how using a combination of these proxy measures can be used to accelerate genetic gain in ruminant breeding schemes. We will describe a program under development to validate these results in beef and dairy cattle and present results to date.

Keywords: methane emissions, rumen microbial profile, genomic prediction, fatty acid, multiomics

Research to Investment: Ensuring climate finance can support the LMIC livestock sector

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There are multiple global ambitions to support net zero pathways for livestock; these include legislative targets and initiatives. Climate finance exists so that countries can innovate and deliver on emissions mitigation goals and to support adaptation to climate change impacts. Livestock production contributes to greenhouse gas emissions (GHGs) and at the same time, livestock systems, particularly in low and middle-income countries (LMICs), are impacted by environmental change. As such, there is a need to reduce livestock emissions, now and in the future, through improving the productivity of LMIC production systems; as well as ensuring these systems are resilient and can adapt to the changing climate. However, to date, climate finance has not widely funded these livestock development projects, due to climate finance barriers (World Bank, 2021). Addressing the needs of the sector in terms of responding to climate impact or reducing emissions (Bonilla-Cedrez et al, 2023) would bring co-benefits such as reduced poverty (improved livelihoods) and improved food security (better nutrition). There is increasing interest from those managing livestock development projects to access climate finance and from financiers to support the sector, particularly with signatories to the Global Methane Pledge. Climate finance pledges are expected to increase year on year and could play an important role in de-risking investment in livestock production system development. Despite this timely opportunity for livestock development, barriers frustrate the allocation of climate finance to livestock development, including specific data and evidence challenges. The Livestock Data for Decisions (LD4D) network is increasingly solutions orientated and a first target for actionable outputs is at this nexus between livestock development and climate finance. Through this paper we would like to report on progress and learnings.

One of the first data and evidence challenges identified was the ability to select the right tool or methodology to assess the climate impacts associated with a livestock development project. In response to this, LD4D collaborated with the Clean Air Climate Coalition (CCAC) to develop a dashboard of available tools (available at https://livestockdata.org/news/find-right-tool-assess-environmental-impacts-farming). The dashboard presents the details of tools in a user-friendly format, to support environmental assessment at project, local, national and international scales. The platform is still being updated and practical case studies are to be added very soon.

Furthermore, LD4D has recently established a Climate Finance Solutions Group. This is the first example of an LD4D solutions group, convening experts from a range of stakeholder organisations (including the Food and Agriculture Organization (FAO), the World Bank, International Livestock Research Institute (ILRI) and the Global Research Alliance (GRA)) to propose solutions for specific livestock development climate finance data and evidence challenges. The group, that includes experts from agriculture, policy and financing sectors, will continue to collaborate through the year, with written outputs planned for November 2024. Success of this group will be measured by the increased mobilisation of climate finance to support mitigation and adaptation plans for the livestock sector in LMICs.

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Keywords: climate finance, low- and middle-income countries, data, overcoming barriers, action-orientated

Assessing Carbon Footprint Variability in Lupin Cultivation: Implications for Climate Change Mitigation Strategies

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Introduction

Reducing greenhouse gas (GHG) emissions from agriculture is crucial in combating climate change, as this sector contributes significantly to GHG levels, including nitrous oxide (N2O) emissions. Implementing economically feasible and socially acceptable mitigation practices is imperative. Narrow-leaved lupin (Lupinus angustifolius), a legume well-suited to temperate climates with impressive nutritional qualities, has the potential to reduce carbon footprints associated with agriculture and human nutrition (van de Noort, 2016). Its high content of unsaturated fats and proteins surpasses that of lentils and chickpeas. Additionally, its ability to fix atmospheric nitrogen through symbiotic relationships with soil bacteria reduces reliance on synthetic fertilizers, a major source of GHG emissions in crop production (van de Noort, 2016). By being processed into protein-rich plant-based milk and meat substitutes, lupin can significantly contribute to reducing the carbon footprint of the German food sector.

This study explores how narrow-leaved lupin cultivation in Germany changes over time and space, crucial for evaluating its sustainability and impact on climate. We aim to understand how lupin growth patterns relate to greenhouse gas emissions and its potential for mitigating climate change in key German growing regions.

Material and Methods

In this study, we analyzed greenhouse gas (GHG) emissions from various lupin genotypes across 14 sites in Germany's main growing regions from 2002 to 2015. Data were sourced from post-registration variety trials published in annual reports by state-level authorities (e.g., Jentsch et al., 2017; Zenk et al., 2017). The dataset includes genotype-, location-, and year-specific yield information (grain yield, thousand kernel mass, grain protein content) and management data (timing, type, and amounts of sowing, fertilization, plant protection measures).

GHG emissions associated with lupin cultivation were quantified using a life cycle assessment (LCA) approach, considering all cultivation stages from land preparation to harvesting. The system boundary was defined from cradle to farm gate, specifically focusing on CO2 emissions. Emissions from material and energetic inputs (e.g., diesel for field operations) were estimated using emission factors from established databases, while N2O emissions were assessed using the IPCC Tier 1 approach. Lupin cultivation for all genotypes, locations, and years was assumed to occur on a 500-hectare farm with an average plot size of 20 hectares and an average farm-to-field distance of 4 kilometers. Data management and LCA calculations were performed using R Studio to quantify GHG and CO2 emissions. Functional units considered were GHG emissions per unit land (carbon footprint land; CFPL), per unit grain (carbon footprint grain; CFPG), and per unit protein (carbon footprint protein; CFPP). Statistical tests, specifically ANOVA, were utilized to assess significant differences in CFPL, CFPG, and CFPP among genotypes, locations, and years

Results and Discussion

Across numerous combinations of lupin genotypes, locations, and years, the carbon footprint per unit land, grain, and protein was assessed. Notably, N2O emissions were identified as the leading contributor to total greenhouse gas emissions in lupin cultivation, followed by emissions from diesel use, seed sowing, and fertilizer application. Greenhouse gas emissions from plant protection products remained low due to minimal usage. Significant

differences were observed among genotypes, locations, and years for all functional units investigated. While there is limited potential to further reduce N2O emissions concerning the carbon footprint per unit land, advancements in breeding and management practices could enhance the carbon footprint per unit grain and protein. To comprehensively evaluate the climate change mitigation potential of lupin and other legumes, conducting a life cycle assessment at the crop rotation level is planned, considering lupin's role in substituting mineral nitrogen for subsequent crops. Additionally, employing agroecosystems models and adopting a model-based Tier 3 approach for estimating N2O emissions will enhance the analysis. Plans also include broadening the assessment to encompass the entire value chain, from production to consumption, to fully assess the climate change mitigation potential of regionally produced lupin-based proteins

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Keywords: lupin, greenhouse gas emissions, climate change mitigation

Policy, gaps, challenges, strategies and opportunities of livestock methane mitigation and adaptation in Bangladesh

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The rising demand from emerging low- and middle-class people worldwide will lead to higher incomes with diver's products. As a result, the global demand for livestock products is projected to rise by 70% by 2050 (FAO, 2019). In this sense, livestock and animal-sourced foods will play a significant role in supplying the growing demand for products originating from animals, improving livelihood, reducing poverty, increasing food security, improving health and nutrition, and achieving gender equality (Adesogan et al., 2020; Iannotti et al., 2021). In Bangladesh, the production of milk has increased by a factor of 4.5 (from 23.7 lakh MT to 106.8 lakh MT) between 2009–10 and 2019–20, which needed to be increased. Similarly, meat production has risen by a factor of 6.09 (from 12.6 lakh MT to 76.74 lakh MT) during the same period (Hossain et al., 2022). Two difficulties currently confront the livestock industry in Bangladesh. First, low animal productivity with poor quality roughages remains a significant problem. Low-quality feed resources and poor physiological systems are therefore responsible for high enteric methane (CH_4) emission, which leads to greenhouse gas (GHG) and environmental pollution. The emission of CH_4 in the rumen is also a process that wastes energy. The impact is a reduction of 6–10% in gross energy intake (GEI) or 8–14% in digestible energy intake (DEI) of ruminants (Okine et al., 2004). In 2020, the livestock sector of Bangladesh was estimated to produce 30.1 Gg of CH_4 (CO_2e), whereas it emitted 26.7 Gg of CH_4 in 2005; over 15 years, CH_4 production gradually increased due to enteric fermentation (Das et al. 2020). Further, as per IPCC (2023) Tier-1 method, the annual average enteric methane emission by dairy cattle, other cattle, buffalo, goat and sheep were estimated at 10812, 11744, 2085, 3368 and 478 Gg (CO_2e), respectively, which represent about 38, 41, 7, 12, and 2% of enteric methane emission from dairy, other cattle, buffalo, goat and sheep, respectively. According to the Paris Agreement (PA), Nationally Determined Contributions (NDCs) aim to secure reaching net-zero CO_2 emissions by 2050 and drop emissions to as low as 43 percent by 2030. Addressing climate change by 2030 is a crucial objective set by the United Nations (UN) as part of the Sustainable Development Goals (SDGs). To address the climate change issues especially from livestock, the Government of Bangladesh has prepared a good number of policies and plans which are place in different sectors, but still there are several challenges in livestock sector. Therefore, this paper reviews the policy, gaps, challenges, strategies and opportunities for livestock enteric methane mitigation and adaptation to reduce the livestock sector's contribution to climate change. The main objectives are to: (i) analysis the climate change on livestock production; (ii) delineate the impacts of livestock methane emission on climate change and (iii) recommend the adaptation and mitigation strategies of livestock enteric methane emissions.

Keywords: available policy, impacts of livestock production on climate change, strategy recommendations for mitigation and adaptation

Food Demand as a Driver of Change: India's Low Carbon Development Strategy

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India's commitment to low carbon development in agriculture includes measures such as promoting sustainable practices, improving irrigation efficiency, adopting climate-smart crop varieties, and enhancing carbon sequestration through agroforestry and conservation agriculture. These strategies aim to reduce greenhouse gas (GHG) emissions while increasing productivity and resilience in the agricultural sector, which, in last five decades has been driven by the Green Revolution and policies surrounding the goal of increasing agricultural productivity to meet food security of the growing population (Pingali et al. 2019). Driven by a multitude of subsidy programs –fertilizer, power, seed, and machinery and complemented with price support policies, this approach provided the much-needed boost to India's productivity growth over the years.

However, this growth necessitated extensive use of inputs including water and land resources. The interconnected nature of the agricultural sector, environment and natural resources were overlooked in the policy framework. As a result, food systems in the country face critical challenges in agricultural production, farmer livelihoods, consumer welfare, and degradation of natural resources, where isolated interventions often overlook the systems approach. Discussions on transforming India's food systems have largely treated agricultural advancement, food and nutrition security, and biodiversity conservation as separate entities (Hinz et al. 2020). This siloed approach hinders the holistic development and sustainable transformation of India's food systems.

In this paper, we use a tool developed by the Food, Agriculture, Biodiversity, Land use and Energy (FABLE) Consortium - FABLE calculator (Mosnier et al. 2023). We focus on the agriculture, forestry and other land use (AFOLU) sector to ascertain India's potential food systems transformation. We use this to create pathways for India's agricultural development: a business-as-usual (BAU) scenario and an ambitious sustainable pathway (SP) aligned with India's commitments to achieving multiple SDGs, with demand side measures such as food demand as determining factors across pathways. Indian diets are mainly based on cereals and include high fat, sugar, salt (HFSS) foods, lacking nutritional security. In the sustainable pathway, we consider dietary recommendations by National Institute of Nutrition (NIN), higher agricultural and livestock productivity and environmental commitments for afforestation such as the Bonn Challenge (26Mha afforestation by 2030).

We find that in the BAU, cropland requirement expands by 24% by 2050, whereas in the SP, this requirement decreases by 7%. Similarly, GHG emissions in the BAU scenario rise by 21% by 2050, whereas in the SP, a 13% reduction is observed. Conserved biodiversity areas also expand in SP by 43%. We conclude that it may be possible for India to achieve multiple SDG targets with focus on implementation of commitments. We also present a pathway approach to identify synergies and trade-offs across multiple goals of the food-land-energy nexus.

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Keywords: India, food systems, dietary change, GHG emissions

Lifecycle assessment of restorative strategies of peatland in the United Kingdom

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Peatlands are terrestrial ecosystems that act as naturally occurring carbon sequestration systems, locking in carbon in waterlogged conditions. Peatlands currently occupy 3% of the global land mass, storing up to 20 Gt CO_2 per year. However, due to degradation primarily driven by anthropogenic activities, peatlands have become a significant source of land-use GHG emissions. The UK's peatlands emit 23 Mt CO_2 per year, accounting for 4% of the total GHG emissions.

The restoration of degraded peatland centres on reversing the effects of drainage by re-wetting and peat management to levels that favour carbon accumulation within the peat layers. Such interventions include surface profiling, maximising carbon input, suppressing GHG emissions and minimising decomposition. Central to peatland restorative strategies is the promotion of paludiculture – the profitable agricultural establishment of wetland crops such as *Miscanthus* spp. In addition to facilitating the raising of peatland water tables, paludiculture crops have the added advantage being used for energy and biobased products. Within the scope of the intervening activities, biochar production and application can enhance the CO_2 sequestration of peatlands.

This work therefore presents a suite of options to produce bioenergy crops and biomass feedstock on rewetted peatlands via integrated biochar-bioenergy-farming systems for downstream processes. This work quantifies the environmental impacts and, subsequently, the greenhouse gas reduction (GGR) benefits of administering proposed restorative strategies on dedicated UK peatlands. Attributional lifecycle analysis is conducted with field data from demonstration peatland sites, analysing the GHG balance across the system. The in-house model highlights environmental hotspots across the supply chain for optimisation and GGR opportunities for future peatland restorative strategies. The analysis investigates GHG reductions in peatlands and the co-benefits producing bioenergy crops towards emission reduction contribution to renewable energy supply. The environmental benefits of nature-based and geoengineered amendments are compared in the analysis.

Subsequent analysis considers the implications of the strategies on counterfactual changes of other linked services via a consequential assessment. The outcomes provide insight into the economic viability of large-scale peatland restorative strategies in the UK.

It is estimated that the restoration of 1 Mha of the UK's peatlands can achieve 1 Mt CO_2 of storage per year. The consequence of this work feeds into a conglomerate of GGR strategies that support the UK's Net Zero ambitions and Paris Agreement 2050. The outcome of this work provides evidence and informs land managers, policy decision-makers and industrial and research stakeholders on the environmental and socio-economic trade-offs and co-benefits associated with peatland GGR measures and opportunities to sustainably add value via paludiculture to produce bioenergy crops.

Keywords: peatland, greenhouse gas, bioenergy crops, climate change, lifecycle assessment, carbon dioxide, CGR

Accounting for the seasonality of livestock derived GHG emissions with GLEAM: a case study in Mongolia

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Mongolia has growing number of ruminant animals such as cattle, sheep and goats that are kept on pasture throughout the year. The livestock sector in Mongolia is facing escalating challenges due to pasture degradation paired with extreme weather patterns and seasonal shifts, such as severe winters and droughts. Conventional methodologies for calculating greenhouse gas (GHG) emissions, largely based on annual data and employing Tier 1 approach, fail to capture these intricate seasonal dynamics. This oversight undermines the development of tailored, potent mitigation plans. Addressing this deficiency, our study incorporates the FAO's Global Livestock Environmental Assessment Model (GLEAM), which follows Tier 2 IPCC guidelines, to evaluate direct GHG emissions (CH_4 and N_2O from enteric fermentation and manure magagement) from ruminant livestock in two Mongolian soums, Altanbulag (A) and Khashaat (K), throughout the four seasons (winter, spring, summer and fall).

Our results indicate that total emissions from the two soums reached 0.1 Mt CO_2eq. The distribution of emissions varied according to the predominant livestock species in each soum. In Altanbulag (39 thousands livestock units), cattle were the principal emitters, accounting for 42% of emissions, followed by sheep at 36%, and goats at 22%. In Khashaat (37 thousand livestock units), sheep led the emissions at 41%, with cattle close behind at 36%, and goats at 23%. Notably, 90% of these emissions stemmed from enteric fermentation, which highlights its significant contribution to the sector's GHG output.

The seasonal analysis uncovered a trend of reduced emissions in winter (A: 250; K: 290 tCO_2eq/day) and spring (A: 291; K: 305 tCO2eq/day) , with a rise in summer (A: 376; K: 436 tCO_2eq/day) and fall (A: 394; K: 431 tCO_2eq/day) This pattern is predominantly due to fluctuations in enteric fermentation emissions, influenced by changes in animal weight, dry matter intake (DMI), and environmental temperature. For instance, during the harsh winter, animals experience significant weight loss of up to 30% due to adverse weather conditions and inadequate feed, leading to lower DMI and GHG emissions. Other crucial aspects are represented by seasonal changes in milk productivity, feed composition, and diet quality. Diet digestibility, which is known to be inversely related to enteric methane, fell by 7% from winter/spring (range: 53-55%) to summer/fall (range: 49-51%). This decline in feed efficiency is reflected in relatively higher emissions during the summer and fall months. Manure management emissions also showed seasonal variations, although less pronounced. Spring saw the lowest emissions (A: 26; K: 44 tCO_2eq/day), with an uptick in the fall (A: 34, K: 63 tCO_2eq/day). These changes are largely ascribed to shifts in the rates of volatile solids and nitrogen excretion, which are in turn driven by variations in dry matter intake, livestock productivity, and temperature.

In conclusion, the application of the GLEAM model to Mongolia and the inclusion of seasonal factors in GHG emission calculations signify a substantial methodological leap forward. The insight provided in this study could provide guidance for a more extensive application of the methodology at a national scale to refine Mongolia's emission profile, allowing to further tailor mitigation plans based on realistic emission scenarios considering seasonal dynamics.

Keywords: GLEAM modeling, seasonal emission, cattle, sheep and goat

Transforming Food Systems in Colombian Amazon: Towards LEFS Through Participatory Research

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The intertwining of food and agriculture with climate change poses significant challenges and opportunities globally. Food systems, responsible for one-third of anthropogenic greenhouse gas emissions and covering 37% of Earth's surface, are central to achieving Sustainable Development Goals (SDGs). In Colombia, particularly in the Amazon, rampant deforestation persists, with agriculture contributing substantially to emissions. Despite this, Caquetá's vast forest cover offers a crucial opportunity for emission mitigation.

Participatory research emerges as a potent tool to address these challenges, allowing communities to shape transformative actions. Through the Mitigate + initiative, a mixed-methods study was conducted in Caquetá's Montañita and Belén de los Andaquíes municipalities, emphasizing cocoa and livestock systems. Employing participatory rural appraisal, in-depth interviews and agroecological structure (MAS) analysis, the study explored the sustainability of local agrifood systems, emphasizing inclusivity for women and youth.

Our results suggest that, despite the importance of livestock and milk as the main economic activity within the livelihoods of rural communities, production systems are diverse. There is a wide variety of food crops for self-consumption and commercialization. Such diversified production can be the foundation of sustainable low-emission food systems that can also support food security. Regarding the results of the MAS, we observe a potential for transitions towards sustainability as producers demonstrate a significant degree of environmental awareness and recognition of biodiversity functions, as well as attempts to implement sustainable practices. However, there is a need to strengthen ecosystem-related criteria, such as live fences, to increase biodiversity and improve the ability to adapt and mitigate climate change.

Supporting these diversified systems with an emphasis on conservation and low-emission practices can strengthen efforts to transition towards sustainability, contributing to food security. This requires considerations beyond incentivizing sustainable practices such as organic production or agroecology through price premiums but also improving market conditions. The lack of infrastructure that would make productive activities economically viable, apart from cattle ranching, needs to be addressed. This need contrasts with the technical assistance and credit available to producers, which are centered on increasing yield and quality but not a more comprehensive measure of sustainability that considers biodiversity conservation, food security, and climate change mitigation. Therefore, to promote sustainable food systems, supporting services such as technical assistance and credit should address integrated and diversified systems to ensure family income and food security rather than treating them as specialized systems based on monocrops.

In addition, a comprehensive approach to sustainability in food systems should include the interests and needs of women and youth. We found that women’s and youth’s participation and decision-making in food systems need to be reinforced. Although women’s participation has increased in production activities and producers’ associations, key decision-making is still in men’s domain, and women face an inequitable load of work and responsibilities, particularly in the reproductive sphere. Youth interests are not considered in food systems, which, together with the threats associated with violence and illegal economies, force young people to migrate.

Keywords: participatory rural appraisal, main agroecology structure, low emission food systems, mitigation, Colombian Amazon

Environmental performance of dairy farms using the Integrated Farm System Model

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Dairy farms are essential for meeting global milk consumption needs; however, concerns about greenhouse gas emissions have raised ongoing efforts to evaluate their environmental impact. To assess this comprehensively, whole-farm models that integrate factors such as management practices, animal husbandry, and manure emissions can be used as valuable tools. Therefore, we aimed to evaluate the environmental performance of organic-certified grass-fed (OGF) vs. conventional (CON) dairy farms and, within each system, to explore the influence of two breeds (Holstein vs. Jersey) using the Integrated Farm System Model (IFSM). An average OGF farm was modeled with 50 milking cows, 90 ha of grazing area, and annual milk production of 4,203 kg per cow, based on data from 106 dairies surveyed in 2019 across six states in the Northeastern United States (Massachusetts, New Hampshire, New York, New Jersey, Pennsylvania, and Vermont). The CON farm model was calibrated using data from the Miner Institute (Chazy, NY) averaged over three years (2019–2021), representing 483 milking cows, 456 ha of land, and an annual milk production of 11,829 kg per cow. Initial simulations compared the environmental performance of the two production systems, followed by an assessment of the impact of Holstein vs. Jersey cows under the same conditions. The IFSM simulations revealed that the average OGF farm had an annual carbon footprint of 1.30 kg of CO_2eq/kg of fat and protein corrected milk (FPCM), whereas the CON dairy farm emitted 0.95 kg of CO_2eq/kg FPCM. Within the OGF system, Jersey cows had a 12% lower carbon footprint than Holsteins. However, in the CON system, no substantial differences were observed between breeds, with carbon footprints of 0.94 and 0.96 kg CO_2eq/kg FPCM for Holsteins and Jerseys, respectively. These findings suggest that OGF dairy farms with Holstein cows emit more carbon to the environment per kilogram of FPCM than that of CON dairy operations, indicating that Jersey cows might be more environmentally suitable for OGF systems. Management strategies that enhance milk production while reducing greenhouse gas emissions are crucial for improving the environmental sustainability of both conventional and organic dairy systems. Future research should explore novel management interventions, such as supplementing seaweed products, which may help accomplish both aims.

Keywords: carbon footprint, dairy cows, life cycle assessment, production system

Low carbon paddy rice cultivation under slow-release N fertilizer management for enhanced rice productivity through C sequestration and GHG mitigation in Vietnam

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Vietnam is among the countries that will be most seriously affected by climate change. At the same time total greenhouse gases (GHG) emissions in Vietnam were 266Tg of carbon dioxide (CO_2) equivalents in 2010 (including LULUCF) and are projected to increase to 466 million tons in 2020 and 760.5 million tons in 2030 (MONRE, 2014). Agricultural production activities emitted 88.3Tg CO2, accounting for 33.2 % of total national GHG emissions. Rice cultivation is considered to be the greatest source of agricultural GHG emissions in Vietnam, with, CH_4 and N_2O emissions estimated to equal 44.8Tg CO_2 equivalents, accounting for 50.5 % of total agricultural GHG emissions in 2010 (MONRE, 2014). Vietnam INDC aim to reduce 30% GHGs for time period 2021 to 2030.

Rice farmers also apply urea (40-60% of total N fertilizer) which can increase N loss via NH_3, N_2O. Using urease and nitrification inhibitors has the potential to reduce NH_3/N_2O losses to the atmosphere. However, limited studies have been conducted using these amendments in Vietnam.

This study aims to i) to determine CH_4 & N_2O emission (using the static chamber technique), NH_3 lost (using chamber method) under the effect of urease and nitrification inhibitors and biochar, ii) to determine NUE of different nitrogen fertilizers using the ^{15}N technique and iii) to develop guidelines of climate-smart agriculture practices for C sequestration, mitigation of GHG, improved N use efficiency to enhance crop productivity.

The field experiment was conducted in fluvisol in spring and summer paddy rice seasons of 3 continuous years (2021, 2022 and 2023) in Vietnam except spring season 2021. The field experiment was layout by RCBD include 4 treatments with 3replication for each of 4 treatments resulting in 12 plots. In which treatment 1: ^{15}N urea; treatment 2: ^{15}N urea + 2 tone of biochar; treatment 3: ^{15}N urea + n-BTPT; treatment 4: ^{15}N urea + DCD.

Applying Urea-nBTPT fertilizer in the 2022 crop and spring 2023 crops has reduced NH3 emissions (19.3% and 22.7%), and N2O emissions (10.8% and 63.8%), increasing nitrogen use efficiency (41.7% and 42.4%) and increasing crop yield (22.6% and 24.7%) compared to traditional urea fertilization formula.

Applying Urea-polymer fertilizer in the 2022 crop and spring 2023 crops has reduced NH3 emissions (37.5% and 6.9%), and N2O emissions (1.0% and 31.6%), increasing nitrogen use efficiency (60.2% and 31.2%) and increasing crop yield (21.2% and 13.6%) compared to traditional urea fertilization formula.

Urea-biochar fertilization in the 2022 crop and spring 2023 crops has reduced NH3 emissions (18.2% and 9.9%), and N2O emissions (29.2% and 54.8%), increasing nitrogen use efficiency (23.9% and 26.3) and increasing crop yield (8.3% and 12%) compared to traditional urea fertilization formula.

Thus, urea fertilizer coated with n-BTPT and polymer has the potential to reduce NH3 emissions, reduce N2O emissions, increase agronomic efficiency, increase nitrogen use efficiency and increase rice productivity.

Acknowledgement

This study was funded by Ministry of Agricultural and Rural Development via the Project '' Application of 15N stable isotope marker technique to improve the nitrogen use efficiency in rice cultivation on alluvial soil of the Red River'' and was also core supported by Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture via ''Coordinated Research Project on CRP D1.50.20''.

Keywords: reduce N2O, NH3, increase nitrogen use efficiency and rice grain yield, NDC, contribute to project ''1 million low carbon rice''

FarMoRe – A potential tool for monitoring and reporting GHG mitigation results in rice production

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Vietnam has made strong commitments to reduce Greenhouse gas (GHG) emissions. In its Nationally Determined Contributions, Vietnam has set ambitious targets of reducing 12.4 MtCO2e from agriculture with domestic resources and additional 50.9 MtCO2e with international support. Additionally, Vietnam has joined the Global Methane Pledge and committed to take actions to reduce methane emissions by 30% by 2030 compared to the 2020 levels. According to Vietnam's Third Biennial Updated Report, the Agriculture, Forestry and Other Land Use (AFOLU) sector contributed to 62% of the country's methane emissions in 2016. Rice cultivation was the largest methane source, responsible for 75% of CH4 emissions from the AFOLU sector. Therefore, the rice sector is a priority to achieve the nation's mitigation targets.

To achieve verifiable mitigation results in the rice sector, effective tools to track and validate GHG mitigation progress and outcomes are crucial. This requires monitoring rice farming activities at field levels to (1) estimate GHG emissions season to season, and (2) introduce interventions or improved low-emission practices properly. Farm household surveys are generally cost and labour intensive and thus not sustainable in the long run.

The Farm Activity Morning and Reporting (FarMoRe) tool, developed by the International Rice Research Institute with support of IFAD-EU, offers a cost-effective solution. FarMoRe provides a standardized set of questions aligned with IPCC protocols for collecting data required for GHG calculations. The tool automates these calculations, presenting GHG emissions (kg CO2e/ha/season) immediately after data submission. Beyond emissions data, FarMoRe offers valuable insights into field management practices like seed rate, fertilizer use, and aeration periods – all factors influencing GHG emissions. The tool visualizes this data alongside scientific thresholds that could suggest potential for improvement. FarMoRe also stores farmers' seasonal GHG emissions data, enabling them to track progress and compare their performance with area averages. Recognizing the context-specific nature of farming, the tool allows users to set their own benchmarks for a more tailored approach.

FarMoRe offers several benefits. It reduces the workload for data collection, calculation, and storage, saving time and resources for both farmers and researchers. The tool ensures reliable data for monitoring mitigation progress and outcomes. Additionally, FarMoRe data can be used to validate aggregated data collected from other sources and remote sensing technologies. The tool's scalability allows application across various farm sizes, from individual households to cooperatives and production units.

FarMoRe has been tested in Can Tho city of Vietnam and received positive feedback on its usability. By streamlining data collection, analysis, and visualization, FarMoRe presents a valuable tool for large-scale rice GHG mitigation programs, such as the recently approved project of Developing 1 million hectares of high quality and low-emission rice associated with green growth in the Mekong Delta of Vietnam. This technology supports sustainable rice production practices and has the potential to contribute significantly to achieving Vietnam's environmental goals.

Keywords: rice GHG emissions, sustainable rice production, MRV tool, low-emission rice

Mitigation measures of crop cultivation to reduce climate impacting emissions from denitrification

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Gaseous emissions from denitrification cause nitrogen (N) losses, which are relevant to crop production and contribute to climate change in the form of nitrous oxide (N2O) emissions from agricultural soils. The joint project 'Measures to reduce direct and indirect climate-impacting emissions caused by denitrification in agricultural soils - MinDen' addresses the topics of reducing nitrous oxide emissions and improving nitrogen efficiency through modeling, the evaluation of possible mitigation measures and the evaluation of denitrification on spatial scale. Climate protection measures in crop production in the areas of fertilization, soil cultivation and crop rotation have hardly been researched with regard to the role of denitrification. Crop management that optimizes N efficiency and minimizes N emissions at the same time has therefore not yet been reliably defined. The overall objective of the present project is to identify practicable crop management measures to minimize N2 and N2O emissions from denitrification for arable cropping systems in Germany by improving the knowledge on denitrification-related N losses through field and laboratory studies and using it for parameterization, validation and application of simulation models.

Our objectives are
- Regionalization of N losses due to denitrification in Germany based on existing models
- Determination of the effect of crop protection measures on N2 and N2O losses on field scale
- Testing of mitigation options on the model, laboratory and field scale, taking into account the topsoil and subsoil for different soils
- Further development of denitrification models to improve the mapping of mitigation measures using existing and new field data
- Testing of mitigation options for Germany using the improved models, taking into account yield, economic efficiency, technology requirements,
- N2O emissions, N efficiency, fertilizer requirements, NH3 emissions and nitrate leaching.

We provide an overview of the approaches and show some of the first insights and findings after the first year of the project. We will show N_2 and N_2O flux data of the field experiment on optimization of slurry application techniques on gaseous N losses, N leaching and N uptake in a maize-wheat crop rotation, were total fluxes were dominated by N_2 and N_2O fluxes mainly originated from denitrification. With respect to modeling, we will present our concept and state of „Calibration-Validation Framework“. Until now comparison of available experimental N_2 flux data shows that existing models severely underestimate N_2 fluxes. But our upcoming field-scale experimental data will be used to improve models step by step.

Keywords: denitrification, nitrogen use efficiency, nitrous oxide emissions, organic fertilization, modelling

Border Carbon Adjustment: Expectation and Implication for Canadian Beef Market

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Border Carbon Adjustment (BCA) is recognized as a solution for carbon leakage issues embedded in unilateral emission policies (Campbell et al. 2021, Winter 2023). Through tariffs or emission permits, BCA charges imports at values proportional to emission prices paid by domestic producers, whereas exporting countries may avoid payments by implementing domestic abatement policies. Several studies show that BCA facilitates large participation in global climate agreements (B¨ohringer et al. 2016, Al Khourdajie and Finus 2020, Iverson 2023). The Canadian beef industry, as an emissionintensive and trade-exposed agricultural division, is set to be affected if BCA is applied to Canadian exports. Given the lack of sector-specific analyses of BCA and the pivotal role of beef in Canada's economy, this study aims to analyze the effects of BCA on Canadian beef prices. Böhringer et al. (2016) identifies three possible responses when BCA applies: cooperate, retaliate, and do nothing. With the same assumption, we derive the equilibrium prices and payoffs of the Canadian beef sector in a partial equilibrium and dynamic game setting, where Canada's beef exports are targeted by BCA imposed by trade partners. In addition to the theoretical relationship between BCA and beef prices, we also verify the results and derive welfare effects numerically using the IMPACT economic model (Robinson et al. 2015). The results will assist the design of environmental policies in the beef sector as BCA rapidly shifts from a theoretical piece to a realized trade policy.

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Keywords: border carbon adjustment, carbon pricing, international trade, general equilibrium model, beef

3 Poster

Abstracts in alphabetical order

Implementation and ex-ante evaluation status of greenhouse gas emissions mitigation policies in the cattle supply chain in Germany

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From farm input procurement to post-consumption, cattle milk and meat affect the climate and other resources use from local to global levels. Despite well-intended, national climate actions, often lead to unintended outcomes as greenhouse gas (GHG) emissions are a transboundary public externality, and policy responsibilities rarely pursue mitigation beyond political borders or when interacting with other sustainability dimensions. With its 2045 GHG-neutral target, a cattle-centered agriculture sector achieving 125% dairy and 98% cattle meat self-sufficiency, and its dairy industry as a major global player, Germany is a crucial case study for evaluating national cattle-climate policies advances.

We conduct a systematic literature review on the status, effectiveness, and trade-offs of German national and EU supranational cattle-climate policies that de facto incorporate Germany. We focus on studies evaluating production, trade, and consumption cattle-climate-related policies within comprehensive equilibrium frameworks that rely on the CO_2 equivalent Global Warming Potential 100 metric.

Of the 25 policies reviewed, 15 remain unimplemented, seven target climate mitigation directly, while the rest influence it indirectly. Only four, focusing on production and trade, have undergone ex-ante evaluations to assess their global net GHG effects, showing minimal mitigation potential or even marginal increases in net emissions.

Most policies potentially trade-offs with other areas, such as animal welfare, soil, and biodiversity conservation, but remain poorly assessed within comprehensive equilibrium frameworks.

Overall, climate policies in Germany's cattle supply chain range from mild and untargeted at production to almost negligible at consumption. Production-related cattle-climate policies primarily rely on voluntary offsets and subsidies, lacking targeted regulatory measures for cattle. This reflects the dominance of broader EU supranational trends favoring monetary incentives over nudges or punitive market-based climate policies. Trade-side policies, such as the EU's Carbon Border Adjustment Mechanism (CBAM), exclude agriculture and, thus, cattle production. In addition, an envisioned broader agriculture accounting into Agriculture, Forestry, and Other Land Use (AFOLU) for mitigation targets and efforts dilutes specific commitments from cattle and other intensive agriculture-related GHG polluters. Efforts to reduce meat and dairy consumption through campaigns, labeling, nudging, and grass-root movements have had little effect. The recent proposal to increase the value-added tax (VAT) on meat from 7% to 19%—if implemented—would represent the country's first direct market intervention to reduce meat consumption, highlighting the need for effective consumption-driven climate policies.

From our review, we draw two main conclusions:

i) To effectively contribute to cattle-related climate change mitigation, Germany and the EU must implement a framework focused on policy net mitigation and reduction targets, derived from comprehensive ex-ante equilibrium evaluations. The EU Green Deal and its Farm to Fork Strategy should extend targets beyond production-side territorial boundaries to include down-stream stages of intensive-GHG supply chains and comprehensive food system policies, internalizing associated emissions and addressing policy-induced leakages.

ii) Addressing research gaps in modeling GHG-emission-intensive value chain-focused policies requires expanding modeling horizons, improving data quality across regions, and true-pricing natural resources. This entails stronger collaboration among economic modelers, biophysical system researchers, and human behavioral scientists. It is crucial to ground policy modeling and decisions in empirical data and ensure that information to consumers reflects policy-consequential outcomes rather than mere product-based attributional emissions.

Keywords: cattle-climate national policies, equilibrium frameworks, cattle GHG emissions, transboundary emissions, trade-offs in sustainability

Evaluate and effectively utilize climate protection potentials of agroforestry

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Climate change together with biodiversity loss, soil degradation, and resource scarcity, represent a significant threat to global agricultural production. Therefore, it is inevitable to promote and adopt climate-smart agricultural practices.

As part of the 2030 Climate Action Programme, initiated by the German Federal government, the JKI (Julius Kühn-Institut) joint project “Evaluate and effectively utilize climate protection potentials of agroforestry” (KlimAF), focuses on modern agroforestry systems, such as alley-cropping systems, as a key component of sustainable and climate resilient agriculture. Alley-cropping systems are a type of agroforestry that alternates rows of woody perennials with rows of crops on the same land, with the potential to mitigate climate change through reduced greenhouse gas emissions while simultaneously removing CO_2 from the atmosphere via C sequestration in biomass and soil (Rigueiro-Rodriguez et al., 2008).

In Europe, one of the main challenges for the adoption of agroforestry practices is a lack of field-based evidence. Therefore, the three-year KlimAF project (June 2023 to December 2026) evaluates the climate protection potential of agroforestry systems and hedgerows in 5 subprojects for dissemination. KlimAF aims to increase our understanding of woody perennials in arable land by field research and to create a corresponding data basis that can be incorporated into model-based, field-specific simulation of productivity and carbon effects. Areas with low yield are determined for optimal spatial implementation of trees. A comprehensive climate assessment and economic evaluation, which takes into account the effects on productivity and the efficiency of material (seed, fertilizer) and energy (diesel) inputs as well as soil carbon effects in addition to the establishment and maintenance of the woody perennials, allows a holistic evaluation to support decision-making. The presentation will introduce the KlimAF project and its subprojects.

Keywords: agroforestry, alley cropping, carbon sequestration

Hermetic structures for safe and sustainable grain storage

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Insects, rodents, and moulds are the cause for losses in stored products all over the world. While the problem is mainly neglected in temperate climates with sufficient food supply, the losses in regions with higher temperatures and most likely underdeveloped infrastructure are significant and add to existing food shortage, especially for vulnerable groups. With climate change, the harvest volume is expected to decrease due to extreme weather events, while losses of stored products can increase due to a change in the occurrence of storage pests. The resulting losses could be compensated by intensifying agriculture. This would lead to increased greenhouse effects by producing additional CO_2. Improved storage is an alternative strategy to reduce both losses and greenhouse gases, which is an aim of the project AVoiD. Hermetic storage which is characterised by gas-tight enclosures, maintenance metabolism of the stored product generates a low low-oxygen atmosphere by respiration, which suppresses harmful pests and fungi.

While hermetic structures such as hermetic bags or silo bags are already commercially available, permanent structures such as hermetic silos are rarely used for the storage of dry stored products. In experiments conducted in underground and above ground silos, the condition of grain will be investigated monitoring O_2, CO_2, temperature, moisture and acoustic signals of potential insect activity. The results will be compared to grain stored in hermetic flexible plastic structures. Additionally, methods of accelerated O_2-consumption are investigated to improve hermetic storage.

In addition, different forms of hermetic storage are compared with other forms of grain storage in terms of environmental, economic and social sustainability criteria in order to determine the most sustainable grain storage technology. Before starting the sustainability analysis, it is important to define the functional unit, the system boundaries to be examined and the impact indicators. The impact indicators to be considered in the environmental sustainability analysis include global warming potential (GWP_{100}) in CO_2 equivalents, human/ecotoxicity (toxicity related impact category), food losses in relation to the resulting emissions and to food security. Economic efficiency is also considered and social indicators such as workload are included in the analysis. First results of these experiments and analyses will be presented.

The aim of the AVoiD project is to develop a hermetic structure that is durable, sustainable, easy to use and affordable for both the European market and small farmers in the Global South. The results of the project would open up opportunities for optimised storage technology under future climate conditions. Although the prospects for application are promising, the climatic, geological and socio-economic differences in the various regions must be considered for successful implementation.

The "AVoiD" project is funded by the German Federal Ministry of Food and Agriculture (BMEL) as part of the Immediate Climate Action Programme 2022.

Keywords: hermetic storage, loss reduction, sustainability, future storage

Crop rotations for enhanced soil C sequestration - A modeling study in southwestern Germany

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1. Introduction

Increasing soil carbon contents is considered as one of the most imperative direction for sustainable crop production contributing to carbon sequestration and enhancing soil properties. The present study explores the potential of increasing soil organic carbon stocks using the process-based agroecosystems model Decision Support System for Agrotechnology Transfer (DSSAT).

2. Materials and Methods

The model was calibrated and evaluated using a comprehensive, high-quality dataset on crop-soil-atmosphere processes assessed over nine years from 2009 to 2018 at six sites in southwestern Germany, freely available from the BonaRes Data Center at https://doi.org/10.20387/bonares-a0qc-46jc (Weber et al., 2022). A 4-year crop rotation was then designed with and without the inclusion of commonly grown non-legume and legume CCs and applied in three cycles at the research sites and the surrounding region. Crop rotation without CCs treatments provided the no-CC scenario, therefore the sole rotation effect could be tested.

3. Results

Results of model simulation of key crop-related variables such as crop phenology, aboveground biomass during the season, and grain/seed yield and key soil-related parameters such as soil respiration and temperature as well as soil organic carbon developments indicated good agreement between simulated and observed data for a range crop rotations comprising several field crops grown in the region with winter wheat (WW), winter barley (WB), winter rapeseed (WR), and silage maize (SM) being the dominant crops.

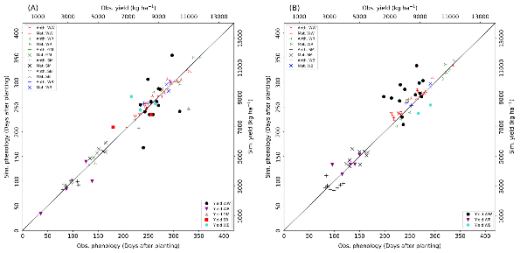

Fig. 1. Comparison of (A) model calibration at sites S1, S4, and S6 of anthesis (Anth.) and maturity (Mat.) and grain yield of winter wheat (WW), winter barley (WB), spring barley (SB), and seed yield of winter rapeseed (WR) and (B) model evaluatzion at sites S2, S3, and S5

Comparison between observed and simulated crop phenology and final grain/seed yield indicated good model performance predicting these crop variables in the (Fig. 1). This was demonstrated by an nRMSE < 10% for the phenology dataset for all crops, except silage maize which had slightly > 10% nRMSE at anthesis, and an nRMSE < 20% for grain yield for all crops except for winter rapeseed which had 21.2% nRMSE in calibration.

4. Discussion

The inclusion of legume CC in the rotation significantly increased yield and water productivity of main crops in the rotation as shown by the N0-L3 treatment in Figure 2. Further, the soil organic N and C have been increased and N leached and N_2O emission have been decreased by this treatment compared with N0-L0 treatment. This could be attributed to the beneficial effects legumes on soil physical and chemical characteristics. Combination

of non-legume and legume CCs treatment indicated an advantage in reducing soil respiration of CO_2 compared with legume only CCs treatment which should be considered for reducing the environmental impact of agriculture (Fig. 2).

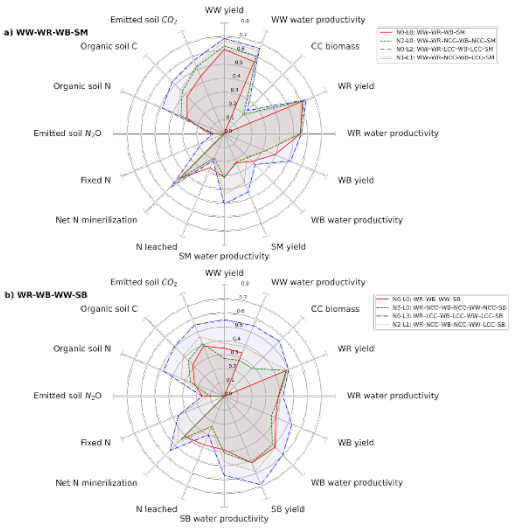

Fig. 2. Radar chart of related soil and crop variables averaged across the 3 cycles of crop rotation from 2006 to 2018 in (A) winter wheat (WW)-winter rapeseed (WR)-winter barley (WB)-silage maize (SM) rotation and from 2006 to 2020 in (B) winter rapeseed (WR)-winter barley (WB)-winter wheat (WW)-spring barley (SB) rotation. The unit of soil and crop yield variables before scaling was kg ha-1 except for water productivity was kg ha-1 mm-1. Cover crop (CC) treatments included control, i.e. no cover crop N0-L0, and non-legume (N) and legume (L) treatments. For instance, N3-L0 indicates inclusion of three non-legume CCs and 0 legume CC and vice versa for N0-L3.

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Keywords: crop rotation, cover crop, soil organic carbon, crop yield, agroecosystem modeling

How does irrigation system transition impact on energy use and greenhouse gas emissions?

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Increasing water scarcity due to global warming necessitates timely investments to build the resilience of the irrigation systems in arid countries like Uzbekistan. The governmental policies in the country promote the adoption of drip irrigation technologies to cope with water scarcity. Yet, energy use and greenhouse gas emission effects of the irrigation system transition are less known. This study develops a dynamic optimization model of irrigation system to analyze optimal transition pathways over time under various levels of water supply reduction scenarios.

The model is applied to examine the effects of drip irrigation technology adoptions on nationwide land uses, energy consumption and related greenhouse gas emissions. As preliminary results indicate, drip irrigation technology are expected to be implemented in more than half of the croplands and increase annual crop production profit by more than twofold by 2100. On one hand, lower water supply requirements and related energy requirements for pumping due to water savings are expected to counterbalance increased energy uses to run the drip irrigation system. On the other hand, energy demand and consequent greenhouse gas emissions increase in the system following the expansion of the drip technology since available water and related energy consumption for water pumping are not impacted by the irrigation system transition. Two main implications of these findings are: first, administrative regulations are essential in case improvements in environmental flow is desired; second, using renewable energy source such as solar energy for running the drip irrigation system and pumping irrigation water is important to reduce the carbon footprints of the irrigation system transition.

Keywords: carbon footprint, drip irrigation, intertemporal investment, water security, Central Asia

Cover crop effects on carbon sequestration and yield in varied climate scenarios

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Agricultural fields represent both a great opportunity for climate change mitigation through soil carbon sequestration and an uncertain prospect under future climate scenarios. Cover crops have been shown to increase soil organic carbon content over time, and may improve resiliency of fields to increasingly likely weather extremes. However, their performance when intercropped with a cash crop is less studied than sequential applications. We investigated the impacts of intercropping cover crops with cereal oat and autumn rye cash crops in varied climate scenarios, focusing on the cash crop yield and field-level carbon cycle, including net fluxes and soil carbon stocks. We calibrated the STICS soil-crop model over two growing seasons (July 2022 - July 2024) using continuous eddy covariance fluxes, chamber flux measurements, and yield observations from an experimental farm on mineral soil in Southern Finland. We then simulated several cropping scenarios including different cover crops such as Italian ryegrass (shallow rooting), clover (shallow rooting and nitrogen fixing), and fescue (deep rooting), alongside varied meteorological conditions. The change in soil carbon stock and net ecosystem exchange will be evaluated alongside the effects on yield, particularly concerning yield stability and resilience to extreme weather conditions. These simulations and modelling capability can influence monitoring, reporting, and verification systems as well as planning and policy decisions related to future agricultural land management, especially the role of cover crops in agricultural carbon sequestration.

Keywords: carbon sequestration, cover crop, climate scenario, STICS

Modelling climate resilience in land use systems

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The planetary boundaries identify nine processes that are central to maintaining the stability and resilience of the Earth system, which are strongly influenced by human activity. Currently, six of the nine boundaries are being crossed, with the ongoing pressure in the areas of climate change and species loss as well as the N- and P-cycles in particular having a massive negative impact on future agricultural production (Richardson et al., 2023). On the one hand, climate change is changing the habitats of animals and plants and thus directly and indirectly threatens biodiversity. On the other hand, biodiversity is of great importance for climate regulation. In particular, the interactions between the biological composition of agroecosystems as well as management methods and environmental factors determine the function of ecosystems and can contribute to adaptation to climate change through diversity (Petersen and Weigel, 2015). Measures to increase climate resilience in agriculture in the sense of insurance and precaution against the effects of climate change can offer a solution and use the synergy between the preservation of biodiversity and the reduction of climate change. In this way, agricultural production systems can be made resilient to the consequences of climate change. Against this background, the aim of this project is to identify the most important measures to increase the climate resilience of agricultural land and to develop a model to assess the climate resilience of land use systems.

First, this project assessed the state of knowledge on 'climate resilience' in the context of agricultural production, in particular land use systems, identified measures to increase climate resilience in the context of land use systems and finally presented them in a meta-analysis. In a next step, indicators for evaluating the climate resilience land use systems will be identified based on these results and by means of an expert survey. Subsequently, a concept for modelling the climate resilience of land use systems will be developed. The final step of the thesis is the operationalization of the model by an intuitive software solution, which captures the ecological impact categories *climate change potential* and *climate resilience/carbon sequestration* as well as economic impact categories based on scenarios. In this way, conflicting goals and synergies between ecology and economy are to be investigated. The modelling of these interactions is intended to show farmers strategies how agricultural land management could be optimized under the conditions of climate change.

The overarching goal of this thesis is to preserve the structures and functions of agricultural production as well as biodiversity and the ability for long-term transformation through adaptation and learning processes.

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Keywords: climate resilience, climate change, adaptation, modelling

Use of low-cost methane ranking system in native sheep and goats of Bangladesh

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Ruminants are a main contributor to the release of greenhouse gases into the atmosphere. The CH_4 is a by-product of feed fermentation in the rumen which is released into the air primarily through eructation by ruminants. There are several methods to estimate the concentration of CH_4 eructated by ruminants; however, most of the techniques are costly and requires highly skilled personnel. Here, a sensor based hand-held gas detector was used to detect the CH_4 concentration of air exhaled into 500-liter plastic tank by 4 sheep and 4 goats. This system is easy to operate and low cost. The measurements were performed pre-feeding and every 30 min for 3 h after feeding (400 g concentrate) repeated on two consecutive days, after adaptation of animal at Chattogram Veterinary and Animal Sciences University (CVASU), Bangladesh animal farm. Methane was recorded at the PPM level by the gas analyser. The CH_4 concentration in exhaled air of sheep and goat increased after feeding and reaches the highest concentration between 1.5 to 2 hours after feeding. At 1 hour after feeding, a significant (P = 0.001) lower CH_4 concentration in sheep compared to goat was observed on both days (15.27% difference), while CH_4 concentrations at the other time points were similar between sheep and goats. The results suggest that sheep and goat each fed 400 g concentrate per day emit a similar average CH_4 concentration.

Keyword: enteric methane, rumen fermentation, gas detector, sheep, goat

The environmental aspect of zinc nanoparticles used in sheep nutrition

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Inorganic zinc sources are routinely used as feed additives for livestock farming; however, excessive Zn content in the diet can lead to the excretion of manure containing high levels of undigested Zn and cause environmental pollution. Therefore, the application of lower doses of zinc oxide nanoparticles indicates an improvement in feeding efficiency and minimizes the excretion of Zn into the environment due to their novel physicochemical properties. Moreover, dietary zinc nanoparticles can modulate ruminal fermentation in terms of the amounts of methane released. The aim of this study was to determine the effect of feed supplementation with zinc nanoparticles on mineral (Zn, Cu, Fe) concentration in plasma and faeces of lambs on day 14 and day 28 of the dietary treatment. The control lambs (6 months old) were fed an unsupplemented diet (350 g/day barley and 700 g/day meadow hay), and diets for the second and third groups were supplemented with 80 mg Zn/kg of diet in the form of phosphate-based zinc nanoparticles (synthesized, ZnP NPs) or ZnO nanoparticles (commercial, ZnO NPs). Intake of ZnP NPs increased Zn and Fe concentration in plasma. Regardless of the source, the addition of 80 mg Zn/kg to the diet elevated the faecal concentration of Zn in both supplemented groups compared to control animals. Zinc nanoparticles were also incubated in vitro in rumen fluid (24-h in vitro gas production method) to evaluate their effect on rumen fermentation parameters (pH, ammonia nitrogen, gas, methane, short-chain fatty acids (SCFA), and microbial population). The SCFA and methane concentration were analyzed by gas chromatography using a PerkinElmer Clarus 500 gas chromatograph (Perkin Elmer, Inc., Shelton, CT, USA). In vitro measurements showed that methane concentration and the total protozoan population tended to decrease more significantly in the zinc nanoparticle groups compared to the control group. The short-term feeding of diets supplemented with zinc nanoparticles at 80 mg Zn/kg diet did not interfere with Cu and Fe absorption and may improve the mineral status in the plasma of lambs. However, the fate of the excreted Zn-nanoparticles and their effect on the environment remain to be investigated.

Acknowledgments: This study was supported by the Slovak Research and Development Agency APVV-21-0301 and APVV-SK-PL-23-0004, and by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V02-00020.

Keywords: zinc, nanoparticles, lambs excretion, fermentation

Using local ensemble models and Landsat bare soil composites for large-scale soil organic carbon maps

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National soil organic carbon (SOC) maps are essential to improve greenhouse gas accounting and support climate-smart agriculture. Recent regulations and frameworks at the national and EU level underline the requirements for and benefits of remote data to monitor carbon emissions in the agricultural sector. As part of the project KlimaFern, we assess the capacity of earth observation and recently developed methods to provide missing information for climate reporting.

Recently, soil reflectance composites (SRC) have been generated from satellite data and used for cropland SOC mapping. However, large-scale models based on wall-to-wall soil information from remote sensing remain a challenge due to the high diversity of natural soil conditions and the difficulty of accounting for the spatial location of the soil samples.

In this study, we tested if the implementation of local ensemble models (LEM) can be used to improve the SOC predictions from Landsat-based soil reflectance composites (SRC) for Germany. For this, we divided the research area into 30 times 30 km tiles and calculated local generalized linear models (GLM) based on random, nearby observations. Based on the GLMs, local SOC maps were predicted and aggregated using a moving window approach. The local variable importance was analyzed to identify spatial dependencies in the correlation between the SRC and SOC. For the final SOC map, a Random Forest (RF) model was trained using the aggregated local SOC predictions, the SRC, and a full set of training samples from the agricultural soil inventory. The results show that the LEM was able to improve the accuracy, compared to the maps based on a single, global model. The local variable importance of the spectral bands showed clear spatial patterns throughout the research area. Differences can be explained by the local soil conditions, influencing the correlation between SOC and the spectral properties. Compared to the widely adopted integration of distance covariates such as geographical coordinates, the LEM was able the reduce the spatial autocorrelation to a greater extent and to improve the prediction accuracy, especially for underrepresented SOC values. The LEM presents a new method to integrate spatial information and increase the interpretability of DSM models.

For the next steps, the generation of the SRC will be optimized to improve the precision and spatial resolution of the SOC maps, including Copernicus satellite data. Based on this, SOC changes will be tracked over space and time. The goal is to create a comprehensive soil monitoring system to fulfill the requirements of the German Climate Protection Law and EU-wide frameworks like the EU Soil Mission and the European Green Deal.

Keywords: remote sensing, soil organic carbon, soil monitoring, greenhouse gas accounting

Modelling the effects of mineral nitrogen fertilisation and ley-rotations on soil organic carbon stocks with RothC - a model evaluation using data from long term experiments

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The soil organic carbon model RothC is widely used and has proven to estimate soil organic carbon changes in top soils of agricultural soils well. However, the model requires estimates of carbon inputs as input variables. Allometric functions are often used to estimate those inputs from yields and it has been shown before that these functions have a high uncertainty, because data to parameterize and evaluate these functions is hardly available. Parameters like the root:shoot ratio are often based on few measurements without information of the representativity of these data sources.

To investigate, how the combination of RothC and selected allometric functions (CCB, IPCC, BZE) can describe soil organic carbon changes in dependence on nitrogen availability and the occurrence of leys in crop rotations we tested these approaches on the Swedish soil fertility experiment conducted on 7 different sites across Sweden. At each site treatments with two different crop rotations (the first one representing a livestock based system including 2 years of leys and removal of crop residues and the second one a cash crop system without leys) were combined with 4 nitrogen fertilisation levels.

Among the chosen allometric functions CCB and IPCC resulted in good predictions of mean effects of N fertilisation level and ley- rotations on SOC changes. However, the approach combining CCB and RothC tended to overestimate SOC trends for ley-rotations. This might be caused by the fact that for leys CCB assumes a constant annual carbon input from below ground biomass. The parameterisation of the CCB approach was based on data from more productive temperate regions (Germany) and therefore this value might not represent the conditions in Northern Europe. Moreover, a yield independent input from below ground biomass in BZE for leys prevented the model to predict the effect of N fertilisation levels adequately. The BZE approach resulted in overestimations of observed trends while the IPCC approach resulted in adequate approximations.

This model evaluation study showed that effects of nitrogen fertilisation and the occurrence of leys in crop rotation on soil organic carbon sequestration can be simulated with RothC. It is sufficient to quantify carbon inputs from crop residues using yield, crop type information and residue management and from organic fertilisation using fertilizer type and application amount. Thus this study further supports the applicability of RothC in scope of GHG emission reporting.

We acknowledge funding from the European Union Horizon 2020 Research and Innovation Programme. Grant Number: 862695 and thank Thomas Kätterer (SLU Sweden) for providing the data of the Swedisch Soil Fertility experiment

Keywords: soil organic carbon sequestration, ley rotation, model evaluation, RothC, crop residues

Converting ungrazed pasture to maize cropping: consequences on soil N_2O emissions.

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Land use conversions are associated with a significant change in soil properties i.e. nitrogen (C) and nitrogen (N), and consequently nitrous oxide (N_2O) emissions. Against the previous context, a 2- year experiment was conducted between 2018 and 2019 to explore the role of converting the cropland from permanent ungrazed pasture to arable maize on N_2O emissions on the cropland and riparian buffers. The treatments implemented were: (i) cropland (3-year old permanent pasture then converted to maize), (ii) no-buffer control, (iii) grass buffer The results showed that the daily N_2O fluxes were generally low (<1 g ha^{-1} day^{-1}) and increased up to ~50 g ha^{-1} day^{-1} in the no-buffer control) immediately after fertilizer application in both the cropland and the riparian buffers when the cropland was planted with permanent. However, immediately when the cropland was ripped, ploughed, and planted with maize, daily N_2O fluxes generally became high higher (> 4 g ha^{-1} day^{-1}) and increased up to ~600 g ha^{-1} day^{-1} in the maize fertilizer application. Cumulative N_2O emissions were larger up to ~ 1.2 kg ha-1 in the no-buffer control and remained low (<0.35 kg ha-) in the riparian buffers before converting the permanent. After converting the permanent pasture to maize, cumulative N_2O emissions of up to ~18 kg ha-1 were observed in the no buffer control) and values remained above 0.35 kg ha-1. The findings of the current study suggest that converting a permanent pasture to maize can result in an air quality concern in both the cropland and riparian buffers installed for water quality functions and where no riparian buffers are not installed bigger air quality concerns may be expected.

Keywords: nitrous oxide emissions, permanent pasture conversion, maize, riparian buffers

Cross-Continental Comparison: Sustainability Indicators in Mixed Crop-Livestock Systems

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Introduction: Mixed crop-ruminant livestock systems play a crucial role in the global agricultural sector. Ensuring the sustainability and circularity of these systems is essential to mitigate environmental impacts and enhance long-term productivity. The selection of indicators for these systems can help translate sustainability assessment into decision-making and action at the farm level, and vary according to specific selection criteria (i.e., relevance and ease of adoption). The INTEGRITY project was set in motion to evaluate the ability of mixed crop-ruminant livestock systems to achieve potential increments of carbon (C) sequestration, nutrient circularity, and sustainability in countries from three different continents (Europe, South America, and Oceania).

Objectives: The objectives of this study were to explore the relevance of selected indicators across representative crop-livestock systems in INTEGRITY-partner countries and to assess if these indicators are an item on mixed crop-livestock farmers' operational agendas using a simple scoring approach.

Material and Methods: The steps for the selection of indicators of sustainability of food production systems were 1) contextualization for indicator selection, 2) literature review in the search for sustainability indicators, 3) screening criteria used for indicator selection and assessment across three dimensions of sustainability (environmental, economic, social), 4) sharing of the survey with INTEGRITY partner countries, and 5) data compilation and analysis. We used a scoring system based on relevance to farmers, data availability, frequency of use, and policy to assess indicators in the environmental, economic and social dimensions of sustainability across eight participant countries, following assessment methodology. Once the surveys were complete, the indicators were grouped into five themes within each dimension.

Results and Discussion: The list of sustainability indicators selected from the literature review included 26 environmental, 21 economic, and 16 social indicators, which were built from the survey shared with INTEGRITY partners. As would be expected from regions in transition towards low-emission production systems, indicators within the Emissions to air theme scored high across countries, with ammonia emissions being the exception in countries with year-round grazing systems. Despite the inherent association between Nutrient losses and Water quality, the sum of scores was numerically greater in the former than in the latter, which could be attributed to economic and/or policy incentives. The sum of indicator scores for the Profitability theme received the highest scores in the economic dimension while the Workforce theme scored highest among the social themes. There is a shortage of literature attempting to understand the broader social and cultural dimensions of sustainability; the social dimension included fewer indicators and had low scores, especially in terms of data availability and frequency of use. Despite the importance of policy context in changing agricultural behavior, analyses specific to mixed crop-livestock systems remain scarce.

Conclusion: The development of surveys with farmers/stakeholders to assess the relevance of farm-scale indicators is important to support direct actions and policies. Future studies, relying on participatory research, should focus on indicators/themes that received the highest and lowest scores, for a better understanding of the factors that oversee those indicators for farmers to increase the adoption of mixed crop-ruminant livestock systems.

Keywords: indicators of sustainability, mixed crop-livestock systems, assessment criteria, environmental dimension, economic dimension

Economic analysis of hay supplementation with *Canavalia brasiliensis* CIAT 17009 in dual-purpose cattle farming in Colombia

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In a world where the demand for animal-sourced food is steadily increasing and the environmental impacts of cattle farming are strongly debated, there is a critical need for both economically and environmentally sustainable and productive cattle systems. However, in regions like the Colombian Caribbean, extensive cattle farming practices are prevalent, often relying on grass monocultures such as *Bothriochloa pertusa* (Colosuana). While this grass performs adequately during the rainy season, its quality and yield decline significantly in drier periods, leading to increased dependence on fertilizers and soil degradation, thereby augmenting production costs and environmental concerns. Against this background, the integration of legumes like *Canavalia brasiliensis* into cattle diets presents a promising solution since it not only improves soil health but also reduces the need for nitrogen-based fertilizers, consequently mitigating greenhouse gas emissions. The present study evaluated the economic benefits of a dual-purpose cattle system in which Colosuana grass is being combined with *C. brasiliensis* hay supplementation. The study examined four treatments, namely (i) a typical Colosuana monoculture, and (ii-iv) Colosuana with *C. brasiliensis* hay supplementation at varying daily inclusion levels (0.5, 1.0, and 1.5% of the liveweight). A discounted cash flow analysis was employed to assess profitability indicators such as Net Present Value, Internal Rate of Return, Benefit-Cost Ratio, and Payback Period for each treatment. The results indicate that all supplementation treatments led to improvements in animal response indicators, resulting in enhanced economic benefits. Profitability increases from 9.30% to values ranging between 16.65% and 18.20%, while the payback period decreased by up to 8 months. These findings underscore the advantages of implementing more sustainable productive technologies in the region. Wide-scale adoption of more efficient systems promises to transition cattle farming to a more intensive yet environmentally sustainable model, thereby reducing its impact on the environment.

Keywords: climate change mitigation, climate change adaptation, sustainable intensification, cattle sector, forage legumes, tropical forages.

Adapting the DSSAT-CROPGRO model for narrow-leaved lupin (*Lupinus angustifolius*)

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Introduction

Increasing the production of legumes is a crucial goal of current agricultural policy in Germany and the EU. Aiding to increase the supply with regionally produced protein, increase crop rotations diversity and help to contribute to climate change mitigation by substituting N fertilizers in cropping systems and by providing alternative plant-based proteins for human nutrition. Narrow-leaved lupin (*Lupinus angustifolius*) shows promise for temperate climate regions. It is traditionally grown in Northeast-Germany but with potential to wider adaption. The anticipated warming trend in the climate is having noteworthy effects on the growth and yield of lupin and hence its suitability in different parts of Germany and other potential growth regions globally.

Process-based agroecosystem models (AEM) assess genotype × environment × management interactions. AEM capture the soil-plant-atmosphere system simulating crop phenological development, growth and yield formation in hourly to daily time steps. The decision support system for agro-technology transfer (DSSAT) is a widely used modelling platform (Jones et al., 2003) that comprises models for more than 40 different crops. Within DSSAT the generic CROPGRO model is available that is parameterized for different legumes, including peanuts, soybean and faba beans. However, there is so far no lupin model available in DSSAT. Hence, this study, we aim to adapt the DSSAT-CROPGRO model for lupin.

Materials and Methods

We´re starting with the CROPGRO faba bean model (Boote, *et al.*, 2002), selected for its similarity to lupin, surpassing other grain legumes' models in terms of similarity (Boote, *et al.*, 2002). We gather available information on lupin's vs. faba bean's morphological, phenological and physiological characteristics from literature, various available experimental data from published sources and available in-house datasets. A valuable source of multi-environment phenological and yield data are the post-registration variety trials. The respective authorities of different states conduct and report those trials annually aiming at informing farmers on regionally recommended genotypes (e.g., Jentsch et al., 2017; Zenk et al., 2017). We further use data from an experiment conducted at the JKI station in Berlin, where four shifted sowing dates were tested annually over three years. The experiment comprises additional data on crop growth, i.e., leaf area index and biomass time series over the growing season. For model adaptation, we decided to go for the common narrow-leaved lupin cv. Boruta first, a cultivar released 2001, which is still cultivated in practical farming up to date.

Boruta is characterized by a determined, i.e., terminal, growth habit featuring a rather clear phenology with little overlap of vegetative and generative growth on the same plant. The assembled dataset encompasses a comprehensive collection of nearly 50 site-years of data for cv. Boruta, providing a robust foundation for our model parametrization. We split the data in ~2/3 for model calibration and ~1/3 for model evaluation.

First, we adapt selected model coefficients building on published sources and define specific coefficients, e.g., maximum grain size, based on analysis of our extensive dataset. For further adapting the model we calibrate multiple cultivar and ecotype coefficients, and utilize the time-series estimator tool (TSE) integrated in the DSSAT framework (Röll, et al., 2020). Notably, this advanced tool facilitates the synchronization of the calibration process across various coefficients and time-series data. Here we first start from phenology parameters, including temperature response, then growth parameters, and finally yield parameters to capture the unique growth characteristics and patterns specific to lupin.

Outlook

The developed CROPGRO lupin model allows the assessment of management options including sowing dates and densities across german production regions under current and future climatic conditions. As a new crop in DSSAT, it enables the assessment of lupin in different crop rotations at various sites. This will allow to thoroughly assessing its potential to substitute synthetic N fertilizer in crop rotations and evaluate its contribution to resource use efficiency. As the DSSAT AEM simulates daily N_2O emissions, the model also allows considering direct and indirect N_2O emissions according to Tier 3 approach in GHG accounting. This allows a thorough assessment of the climate change mitigation potential of lupin cultivation in Germany.

Future improvements include extending the model to simulate indeterminate varieties and enhancing robustness in resembling drought and heat stress. Targeted field and climate chamber experiments are necessary for further model refinement.

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Keywords: crop model, DSSAT, narrow-leaved lupinin, creasing legume production

Potential of healthy pigs using the example of vaccination against *Lawsonia intracellularis*

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Introduction: The emission of greenhouse gases may be determined using the carbon footprint. For pigs, this value is highly linked to the performance of the animals. An infection disease such as an infection with *Lawsonia intracellularis* could result in a negative influence on the performance of the pigs. Consequently, a vaccination against this bacterium may result in a reduction of the excretion of greenhouse gases.

Material and Methods: Based on a literature research focusing on Europe and countries with similar production systems the performance of pigs with and without a vaccination against *Lawsonia intrastellularis* was studied. Out of 41 reviewed studies 16 field studies (published between 2004 and 2022) were used to extract key indicators of performance (live weight, average daily gain [ADG], feed conversion ratio [FCR]) and mortality for groups without an infection and challenged groups. The mean value of both categories was used to perform a life cycle assessment (LCA) to determine the carbon footprint (CO_2 eq per kg live weight) using Opteinics™ (software application conducting life cycle assessments for farming animals). Therefore, it was assumed that all pigs got the same diet based on wheat, barley (both from Germany) and soybean meal (Brasil) as it was used as a control diet in earlier trials. Further consumptions (e.g. energy/fuels) and former/later stages of production where excluded.

Results: Focusing on the effects of a vaccination under field conditions the ADG showed a mean increase of 2.6% compared to related control groups (epidemic infected); the mean FCR was 2.5% lower. The mean mortality decreased from 3.6% to 2.5% comparing the vaccinated to the unvaccinated groups. The calculation of LCAs showed a decrease by about 3.2% in the carbon footprint of the pig with vaccination against *Lawsonia intracellularis* compared to the control groups without a vaccination (using the mean values of start weight, ADG, mortality and the length of the trial).

Discussion and conclusion: Focusing on trials from Europe only very few data deal with the performance of pigs in relation to the vaccination against *Lawsonia intrascellularis* under field conditions. Nevertheless, it could be concluded from this small amount of suitable publications that the carbon footprint of the trial period decreased following a vaccination. Therefore, preventive measures and health monitoring of pigs may be an important parameters to ensure a high level of sustainability in the production of pork.

Acknowledgments: The project was supported by the German animal health industry association (Bundesverband für Tiergesundheit e.V., BfT).

Keywords: carbon footprint, pigs, lawsonia intracellularis, vaccination

Environmental and economic assessment of German oat milk using an integrated LCA-LCC approach

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The trend towards a more plant-based diet and growing concerns about climate change have led to an increasing interest in dairy alternatives in the last years. With a 56% share of the total milk alternatives market, oat milk is currently the most popular plant-based milk in Germany (BMEL 2023). However, the area of oat cultivation in Germany has decreased by almost 40% in the last 20 years: from 230,000 ha in 2001 to 140,000 ha in 2023(AMI 2012; Statistisches Bundesamt 2024). At the same time, only 30% of the oat processed in German mills are of German origin (Müller and Voigt 2023). This gap between the decreasing oat cultivation area and the increasing demand for oat milk in Germany is huge and largely compensated by the international oat trade.

In the TRIP project (in German: Treibhausgasreduktion durch innovative Züchtungsfortschritte bei alternativen pflanzlichen Proteinquellen) we investigate the whole value chain of oat milk (see Fig.1) and apply an integrated Life Cycle Assessment (LCA) - Life Cycle Costing (LCC) approach to assess the status quo of the environmental and economic performance of oat cultivation, processing and oat milk production in Germany. In addition, we conduct a scenario analysis of different greenhouse gas (GHG) mitigation options throughout the whole value chain. We aim to provide different stakeholders in the value chain with a better understanding of different GHG mitigation options and their impacts on GHG emissions and costs, so that stakeholders can make better decisions towards a more sustainable oat milk production.

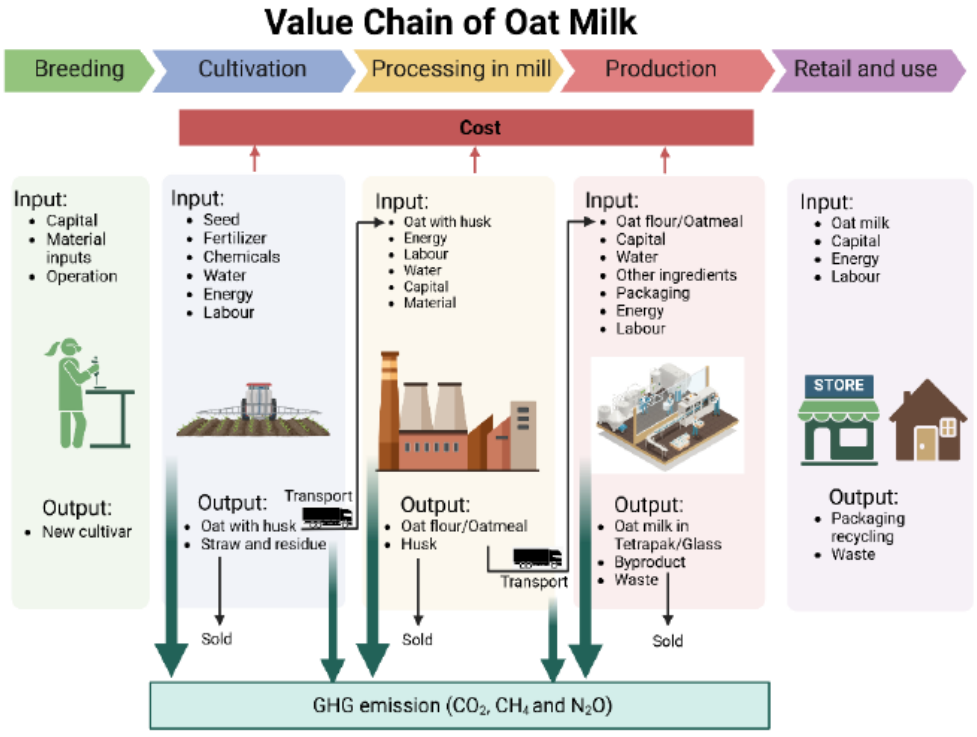

Fig. 1 Value Chain of Oat Milk

The main stages in the value chain of oat milk were identified as breeding, cultivation, processing in the mill, production, and sales and consumption. The scope for an integrated LCA-LCC analysis covers the partial value chain from oat cultivation up to the gate of the oat milk producer. The GHG emission of oat cultivation in Germany is modeled with DSSAT and in a mixed model considering different influences of cultivars, management and environment. Input and output informations from oat processing in the mill and oat milk production are collected through questionnaires.

The first results show that energy consumption in the milling and production phase causes 44.1% of the GHG emissions in the production of 1 liter of oat milk, followed by 30.1% from oat cultivation. In the LCC, packaging is the largest contributor with 46%, followed by 31.5% from milling and production energy consumption and 15.7% from oat cultivation. In the next step, scenario analysis will extend the scope of the value chain analysis up to breeding at the beginning and down to the consumer at the end of the value chain. It will assess the potential of different oat origins, packaging and new varieties to reduce GHG emissions and costs. These potentials will be quantified and ranked according to the economic cost of reducing a unit of GHG emissions.

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Keywords: oat milk, value chain, integrated LCA-LCC approach

Evaluation of soil organic carbon pools dynamics under long term use of farmyard manure and mineral fertilizers

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Farmyard manure (D) in combination with inorganic fertilizer (NPK) trial was started at Samaru Zaria in 1950 to assess nutrient imbalances resulting from continuous use of mineral fertilizer on some poorly buffered soils and to improve and optimize productivity of these soils under intensive agricultural land use. A total of ten treatments, including Nitrogen (N), FYM combined with NPK (DNPK), Control, Phosphorus (P), FYM combined with phosphorus (DP), FYM alone (D), Potassium (K), FYM combined with nitrogen (DN), FYM combined with potassium (DK), and NPK, were selected and evaluated for their impact on total organic carbon (TOC), unprotected particulate organic carbon (UPOC) at 250µm, intra-particulate organic carbon (IPOC) at 50 µm, SOC associated with silt and clay (<50µm), and non-hydrolysable carbon (NHC). The results show that the treatments differed from one another in SOC pools. FYM combined with phosphorus (DP) treatment exhibited the highest TOC levels with 57% higher relative to the other treatments. Conversely, potassium (K) treatment showed the lowest TOC content, approximately 13% lower than the control. Moreover, DNPK treatment had the highest UPOC levels, indicating efficient organic carbon retention in the particulate fraction, with about 59% increase compared to the control. Notably, NPK treatment had the highest SOC associated with silt and clay, suggesting enhanced carbon stabilization, with a percentage difference of about 63% compared to the control. These findings highlight the importance of integrating organic amendments with mineral fertilizers to augment SOC pools effectively for a sustainable soil management strategy aimed at enhancing soil fertility and mitigating climate change impacts.

Keyword: organic carbon, manure, soil organic carbon pools, control and NPK

Whole cottonseed as an alternative to mitigate In vitro methane emissions on low-quality forage-based diets

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Whole cottonseed (WCS) is a by-product from cotton processing used as a cattle supplement. It contains high levels of fat (especially unsaturated fatty acids) and protein and has been reported to reduce enteric methane (CH_4) emissions. Three independent in vitro batch culture incubations were conducted as a randomized complete block design to test the optimal level of WCS inclusion in low-quality tropical forage on in vitro dry matter disappearance (IVDMD), pH, and gas and CH_4 production. Rumen fluid was collected from two cannulated Braford steers. Treatments consisted of increasing inclusions of WCS on guinea grass (GG; *Megathyrsus maximus* cv. Gatton): 0WCS (GG without WCS addition); 12.5WCS (GG + inclusion of 12.5 % WCS); 25WCS (GG + inclusion of 25 % WCS); 37.5WCS (GG + inclusion of 37.5 % WCS), and 50WCS (GG + inclusion of 50 % WCS). Approximately 500 mg of DM per sample were placed into the incubation bottles (125 ml) with the mixture of rumen fluid in 7 replicates and incubated at 39°C for 48 h. After incubation, the bottle content was centrifuged to collect the supernatant for the analyses of pH and the residue for the IVDMD determination. Gas production were measured at 3, 6, 9, 12, 24, and 48 h of incubation (Mauricio et al., 1999). No effect was observed in pH. Gas production had a quadratic response to WCS inclusion, the highest values were found for 12.5 % and 25% of WCS inclusion. IVDMD was not affected by the level of WCS. CH_4 production showed lesser values with a 50 % inclusion of WCS. However, in animals, this level of WCS could exceed the maximum suggested for fat in the diet (up to 6 % DM). Nevertheless, previous in vivo studies suggest that methane production could be decreased with lower levels.

Table 1. Cumulative gas, methane production and *in vitro* dry matter (DM) disappearance (IVDMD) of increasing levels of whole cottonseed inclusion in forage-based diets

	Level of WCS inclusion (%)[1]					SEM[2]	Contrasts[3]		
Item	**0**	**12.5**	**25**	**37.5**	**50**		**L**	**Q**	**C**
Initial pH	6.98	6.92	7.02	7.00	6.92	0.17	0.92	0.80	0.68
Final pH	6.61	6.60	6.60	6.63	6.68	0.07	0.41	0.54	0.99
Gas,ml/gDM	167.30^{ab}	174.74^{a}	173.48^{a}	168.80^{ab}	160.53^{b}	21.71	0.08	<0.01	0.63
IVDMD, %	59.62	60.39	61.04	61.95	60.44	1.19	0.31	0.26	0.47
Methane,									
ml	6.26^{ab}	6.62^{a}	6.31^{a}	6.24^{ab}	5.68^{b}	0.86	0.02	0.03	0.73
ml/g DM	10.91^{a}	11.55^{a}	11.00^{a}	10.88^{a}	9.89^{b}	1.48	0.01	0.02	0.74
ml/ g dDM	18.30^{ab}	19.00^{a}	18.17^{ab}	17.49^{bc}	16.35^{c}	2.11	<0.01	0.09	0.45

[1]Treatments were: 0WCS: only guineas grass (GG), 12.5WCS: GG + inclusion of 12.5 % WCS, 25WCS: GG + 25 % WCS, 37.5WCS: GG + 37.5 % WCS, 50WCS: GG + 50 % WCS. [2]SEM: standard error of the mean. [3]L (linear), Q (quadratic), and cubic (C) effect probabilities for supplementation level

Keywords: methane, forage, whole cottonseed, digestion

Top-dressing 3-NOP on grass silage to reduce enteric methane in non-lactating dairy cows

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Methane emissions from enteric fermentation account for the majority of greenhouse gas emissions from livestock production systems. Feed additives such as 3-Nitroxypropanol (3-NOP) provide a promising solution to reduce enteric methane output. The additive is most effective when mixed continuously through the basal diet, resulting in reductions of 20-30%. However, this strategy represents only one of the differing scenarios which dairy cows are fed on farm internationally. Therefore, alternative strategies are required to supplement the additive. Within pasture-based dairy systems, the majority of an animals feed budget comes from grazed grass. Feeding 3-NOP to grazing animals is very difficult at present with low reductions of ~5% reported. Nonetheless, dairy cows in Ireland are housed indoors during the winter months. Feeding additives within grass silage offers one avenue of feeding the additive, however, this will not be possible where there is no mixing wagon on farm. The current study investigated the effect of top dressing grass silage with 3-NOP on enteric methane emissions of pregnant non-lactating dairy cows as an alternative strategy to supplement 3-NOP. Two groups were compared over a 7 week period; a treatment group and a control group. Both treatment and control groups were fed silage once daily in the morning. The treatment group received 3-NOP top dressed on their grass silage with dry cow minerals twice daily. The control group received dry cow mineral without 3-NOP top-dressed twice daily. Body weight and body condition score were measured weekly, while dry matter intake was recorded on a group level. Enteric methane and hydrogen were measured using a GreenFeed monitoring system. There was no effect of 3-NOP supplementation on dry matter intake, body weight or body condition score. Cows supplemented with 3-NOP produced 11% less methane compared to the control group. Furthermore, a transient effect was noted, with the additive most effective in the time period after each top dressing and gradually waned as the day progressed, with the lowest reductions observed in the early morning hours pre top-dressing. Cows supplemented with 3-NOP also produced 1.8 fold more hydrogen compared to the control group. In conclusion top dressing 3-NOP in a grass silage diet can reduce enteric output by 11% during the winter housing period without impacting performance parameters. These reductions are in the intermediate range of pulse dosing the additive within concentrate and mixing the additive continuously through the basal diet.

Keywords: methane, 3-NOP, top dressing, silage

Tier 2 Protocol for Enteric Methane Emissions from African Cattle

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Accurate monitoring of greenhouse gas (GHG) emissions is fundamental for the advancement of mitigation strategies in African cattle production systems. The Tier 1 method, predominantly used by Sub-Saharan African countries employs broad continental-level activity data, leading to potential inaccuracies, and cannot be identify potential entry points for mitigation. Based on the methodology presented in ILRI Manual 39, which was based on CSIRO's metabolizable energy methodology, we have refined a Tier 2 methodology that uses local animal activity data and dietary specifics, thereby improving the accuracy of emission estimates. Seasonal variations in feed availability and quality, as well as their effects on animal performance, are integrated into the emission calculations, with energy requirements derived from the revised IPCC net energy equations. The revised protocol provides a comprehensive Tier 2 approach for data collection and calculation of region-specific enteric methane (CH_4) emission factors (EFs), in alignment with the Intergovernmental Panel on Climate Change's (IPCC) revised methodology. The EFs, expressed as CH_4 kg/head/year, enable enhanced precision in national GHG inventories and the formulation of locally-adapted mitigation strategies, fulfilling the Paris Agreement's requirements for regular and accurate GHG reporting. While initially targeted at smallholder mixed crop-livestock systems, the revised protocol now extends to pastoral systems, reflecting the diverse African livestock environments. It transcends this foundation by incorporating the globally-recognized IPCC methodology, ensuring international comparability of livestock GHG inventories. The significance of the protocol extends beyond its scientific robustness; it is a practical tool for policymakers, farmers, and stakeholders within the livestock value chain. It facilitates the identification of key emission sources, the assessment of mitigation potential, and the implementation of best practices for emission reduction. As a GHG monitoring tool, it bridges the gap between local livestock management and global environmental standards, supporting the pursuit of sustainable livestock production and climate change mitigation in sub-Saharan Africa.

Keywords: methane emissions, African cattle, Tier 2 Protocol, GHG monitoring, IPCC methodology

What drives recent trends of nitrogen use efficiency and mineral fertilizer consumption in Germany?

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An efficient use of nitrogen is crucial for reducing climate impacts of agricultural production while ensuring food security. In Germany, new national fertilization policies aim at optimizing nitrogen use efficiency (NUE) (e.g. amending fertilizer application ordinance while enhancing principles of good fertilization practice in 2020, or a novel ordinance on nutrient budgeting on farm-gate level in 2018) (Löw et al. 2021) and recent trends in agricultural nitrogen flows point to increasing NUE. However, studies find substantial differences in mineral fertilizer consumption, the main nitrogen input source, and NUE at regional and farm type-level (Löw und Osterburg, 2024; Zinnbauer et al., 2023). Multiple drivers potentially impact on nitrogen management in German agriculture between 2017 and 2023, including extreme drought events in 2018 and 2019 (Klages et al. 2020; Schmitt et al. 2022), volatile input and output prices due to geopolitical conflicts and an increasing role of carbon pricing for fertilizer industry as part of the EU Green Deal (Osterburg 2024). Since these multiple drivers are likely to change in future, we investigate their lasting influence on nitrogen management across different farm types and how effectively policies support the increasing NUE trend.

In order to identify drivers of changes in NUE and mineral fertilizer consumption between 2017 and 2023, we calculate NUE by considering nitrogen input and output parameters at “farm-gate” as system boundary (Quemada et al. 2020; Löw & Osterburg 2024) and use farm-specific and invoice-based fertilizer consumption documentation, based on farm data of the German Farm Accountancy Data Network. Covering around 25,000 observations between the years 2017 and 2023, we develop a multiple regression model to identify effects of regional (e.g. soil fertility), farm-structural (e.g. livestock farming, organic vs. conventional) and individual market-related (e.g. fertilizer prices) characteristics. In addition, we control for initial levels of NUE and compliance with nitrogen policies as well as location in nitrate polluted areas.

The results reveal an increasing trend in NUE for all farm types, from 56% to 77% at sectoral level. Growth rates were most significant in 2021 and 2022, following minor differences previously. Simultaneously, mineral fertilizer consumption decreased notably: from -44% (-27 kg N/ha) for other cattle farms, to -22% (-19 kg N/ha) for pig and poultry farms and -18% (-23 kg N/ha) for arable farms. First results from our multiple regression analysis indicate significant interrelations between increasing NUE and independent variables, such as high soil fertility, organic farming or specific winter grain species in crop rotation. Despite improvements in nitrogen pollution at state and federal levels (LWK Niedersachsen 2024; Umweltbundesamt 2023), there are still farms with excessive nitrogen inputs. Our analysis reveals that farms with a net soil-surface budget above 50 kg N/ha (a regulatory threshold for farms in Germany until 2020) reduced nitrogen fertilizer inputs by 34% over time, their input remains 27 kg N/ha higher and NUE 15% lower than the average for all farms in 2023. Thus, we highlight the need for comprehensible nitrogen policies accompanied with reliable and easily monitored agri-environmental indicators to address farms which are not yet utilizing their NUE potential to the fullest. The analysis contributes to better understand multi-dimensional agri-economical linkages and supports policymakers in designing effective policy measures.

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Keywords: nitrogen policies, nitrogen use efficiency, mineral fertilizer, agri-environmental indicators

Breeding progress reduces carbon footprints of the five major cereal crops in Germany over the past four decades

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This study performs a comprehensive Life Cycle Assessment (LCA) to analyze the impact of crop breeding on yield, greenhouse gas emissions (GHG), and carbon footprint trends the five major cereal crops: winter wheat, winter rye, winter barley, spring barley, and winter triticale, over a 39-year period using the Value for Cultivation and Use (VCU) pre-registration variety trial data. These data comprising several thousand G × E × M combinations collected from all cereal production regions in Germany. By employing mixed model analysis, we were able to distinguish between genetic and non-genetic trends affecting these agricultural traits. Our findings indicate a consistent upward genetic trend in yields across all crops, with winter triticale exhibiting the most pronounced increase due to breeding efforts. However, a plateau in yield trends around the year 2000 followed by a subsequent decline suggests a non-genetic, agronomic impact likely attributed to climate change, with rye being particularly affected.

The analysis of greenhouse gas emissions mirrored the yield trends, revealing similar genetic and non-genetic influences. Significantly, the carbon footprint analysis for these crops showed a downward genetic trend, indicating successful breeding efforts towards sustainability. In contrast, the non-genetic trend displayed an upward trajectory, underscoring the challenges posed by external environmental factors.

These results highlight the critical role of breeding in ensuring food security by not only enhancing crop yields but also in mitigating climate change effects through the reduction of carbon footprints. The study underscores the importance of breeding as a tool for maintaining food production levels while addressing climate mitigation challenges, thereby contributing to sustainable agricultural practices and environmental conservation.

Keywords: life cycle assessment, yield, carbon footprint

Optimizing Carbon Sequestration Potential in Agricultural Lands through Soil Management and Agroforestry Practices: A Bibliometric analysis

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Purpose: This manuscript aims to conduct a comprehensive bibliometric review to analyze the intellectual structure and research trends pertaining to optimizing carbon sequestration potential in agricultural lands through soil management and agroforestry practices. **Methodology:** The study employed a predefined Population, Intervention, and Outcome (PIO) protocol, adapted from the Population, Intervention, Comparator, and Outcome (PICO) protocol, to guide the selection of scientific publications. A search was conducted across titles, abstracts, and keywords of publications in the Web of Science and Scopus databases. Relevant literature spanning from 2000 to 2023 was retrieved using a carefully constructed search string. Data analysis was performed using the Bibliometrix package in R, facilitating the extraction of key insights from the collected metadata.

Findings: The bibliometric analysis revealed significant insights into the evolution of research output, thematic trends, and influential authors and publications within the field. Key findings include a dynamic growth in publication count, particularly from 2009 onwards, with notable peaks in certain years. Analysis of source dynamics highlighted a growing interest in agroforestry systems and environmental management, with specific journals emerging as focal points of scholarly discourse. The study also identified influential authors and affiliations, shedding light on collaborative networks and research productivity. Moreover, thematic analysis revealed prominent topics such as soil carbon management, agroforestry practices, and climate change adaptation, underscoring the multidisciplinary nature of research in this domain.

Research Limitations: While the study provides valuable insights into the intellectual landscape of carbon sequestration in agricultural lands, several limitations should be acknowledged. The analysis is based on keyword co-occurrence data extracted from scientific publications, which may not fully capture emerging or niche research areas. Additionally, the study does not assess the quality or impact of included publications, which may vary widely in rigor and relevance.

Originality/Value: This manuscript contributes to the existing literature by providing a comprehensive overview of research trends and intellectual structures within the field of carbon sequestration in agricultural lands. By synthesizing data from a wide range of publications and employing advanced bibliometric techniques, the study offers valuable insights for researchers, policymakers, and practitioners interested in sustainable agriculture and environmental management.

Conclusion: In conclusion, this study demonstrates the importance of soil management and agroforestry practices in optimizing carbon sequestration potential in agricultural lands. The findings underscore the dynamic nature of research in this field, highlighting key thematic trends, influential authors, and collaborative networks. By identifying research gaps and emerging areas of inquiry, this manuscript provides a roadmap for future research aimed at addressing climate change and promoting environmental sustainability in agricultural systems.

Keywords: agroforestry, carbon sequestration, soil management

Feasibility of a climate-friendly diet in everyday life - a qualitative analysis

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There is great potential to minimise climate-damaging greenhouse gases in consumers' everyday eating habits and food choices. This is because a large proportion of greenhouse gas emissions can be attributed to dietary behaviour. Although there is already a lot of information on climate-friendly eating behaviour, practice shows that this is still implemented too little or too rarely. Since many decisions in everyday life are related to nutrition, it is important to analyse whether a transformation of nutritional behaviour in daily life is feasible and to what extent an understanding of climate-friendly nutrition plays a role in this.

The aim of this study was to analyse what the respondents imagine or know about climate-friendly eating behaviour and to what extent they strive to implement it in their everyday lives. At the same time, we took a closer look at the hurdles that exist from the consumer's perspective and which aspects are considered easy to implement. Therefore, 80 semi-structured interviews were conducted with German consumers in the cities of Munich, Leipzig, Cologne and Hamburg in November 2023. These were analysed using a qualitative content analysis according to Mayring.

From the consumer's point of view, climate-friendly eating behaviour includes regionality, seasonality and reduced meat consumption. However, avoiding packaging and not travelling by car when purchasing food are also associated with climate-friendly eating. At the same time, animal welfare aspects and a self-sufficient lifestyle are part of the understanding. Such a diet is desirable in order to make a contribution to climate protection, because personal benefits are expected or to support regional production. Fear of being restricted by a climate-friendly diet, especially financially, is one of the main reasons for people not to follow it.

When it comes to implementing a climate-friendly eating behaviour in everyday life, the following aspects tend to be fairly easy for people to implement: avoiding food waste, ensuring conscious food preparation, buying locally and avoiding certain product groups where possible. Obstacles to implementation are the associated change in personal habits, for example with regard to not eating meat. Lack of interest or unwillingness to cut out certain products are further difficulties when it comes to implementation.

In summary, the understanding of climate-friendly eating behaviour is often focused on individual aspects and can only be implemented in some areas from a consumer perspective. In order to exploit the potential to reduce greenhouse gas emissions in the area of nutrition by changing dietary behaviour, the hurdles on the consumer side must be specifically addressed. The nutritional environment is of particular importance in this respect, in order to make nutritional behaviour more climate-friendly. Practical assistance must be provided to appeal to consumers' personal responsibility, but the implementation of climate-friendly nutrition in everyday life must also be facilitated by political and economic framework conditions. This means that society, policymakers and industry must be called to responsibility to make a collective contribution to reducing greenhouse gas emissions through food.

Keywords: climate-friendly diet, consumer perspective, nutrition

Holistic planned cattle grazing management as a mitigation measure for GHG emissions reduction in Zambia

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Cattle rearing is one of the main economic activities among traditional smallholder farmers in Zambia, and more than 95% of ruminants in this region are kept on communal grazing lands. However, the communal grazing lands are rarely managed or controlled, leading to overgrazing and decreased pasture quality, thus predisposing them to poor growth rates and low reproductive performance. Though cattle have been reported to be responsible for 62% of livestock GHG emissions through enteric fermentation and manure management, this is further exacerbated by a poor production system. Improving grazing management is an effective approach for increasing animal productivity and reducing GHG emissions (particularly CH4) per unit of animal product or per unit area.

A homegrown, holistic, planned cattle grazing management scheme that borrows from traditional livestock management practices holds the key as a mitigating measure that is expected to lead to changes in farm systems and land management. In partnership with an NGO and a public University, the community (40 individual cattle owners) pooling their herds (about 500 heads of adapted local breeds of cattle) together as a unit, which is then herded by well trained but few herders in a grazing rotation. This was implemented in the Mpanshya communal herd in the Rufunsa district of Lusaka province of Zambia from 2018 to date (6 years).

The study showed that the planned rotational grazing and herding allowed for the pasture's regrowth and regeneration (a long rest period) while enriching the soil with the excreted dung and urine. The improved grass quality will translate to higher digestibility, potentially reducing GHG emissions. Rotational grazing optimizes dry matter intake rate by improving nutrient consumption per unit eating time. The cattle were observed eating together in a high density, high impact rotation, encouraging competitive eating. The animals had fresh grass to eat as they moved from one grazing plot to another. It also did not allow for the selection of forages as all species are eaten evenly without overgrazing and thus guaranteed a balanced diet. The high hoof impact of the cattle moving as a large herd helped to break down hard surfaces and helped to mulch any uneaten grass back into the soil and the possibility of having the grass seeds planted. This allowed for soil cover, thus more water infiltration and soil fertility from dung and urine entrapment. This has led to increased carrying capacity of the grazing land. It was also observed that incidences of diseases and parasitic infestations were much reduced through breaks in the cycles of ticks, parasites and worms as the grazing animals are not sedentary. Body condition scores were found to be better. It is believed that the above has led to enhanced cattle adaptability and resilience to climate change while reducing greenhouse gas emissions from ruminants maintained on communal grazing lands. All of the above are expected to result in a reduction of GHG emissions. However, the quantum of the reduction in GHG emissions will require actual measurement to come up with empirical evidence.

Keywords: cattle, holistic, communal grazing, mitigation, GHG emissions

Predictive machine approaches to estimate nitrogen excretion in dairy cows in Latin America

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The protein metabolism in cattle is crucial for optimizing nutrient utilization, enhancing animal performance, and improving nitrogen (N) use efficiency. Additionally, the N excretion in faeces and urine from cattle generates atmospheric pollution through greenhouse gas, ammonia emissions, and nitrate leaching to groundwater. The N excreted is rarely measured in farms due its cost; therefore, accurate prediction models are needed. Several models have been developed to predict the N use, efficiency, and excretion under temperate conditions but not in the tropics. Thus, the aim of this study was to evaluate different sets of explanatory variables and machine learning techniques to predict the N excretion from dairy using data derived from studies carried out in Latin America. A total of 5 studies including 127 individual dairy cattle records were analysed from Latin American and Caribbean (LAC) dataset, the means values for variables included are dry mater intake-DMI (14.85 kg-d^{-1}), dietary composition (Crude protein-CP: 157.7; Ether extract-EE: 30.3; Neutral detergent fiber-NDF: 426; Acid detergent fiber-ADF: 232.2 and Ash: 81.54 $g.kg^{-1}$ MS), animal body weight (614.9 kg), milk yield (18.25 $kg.d^{-1}$), milk composition (Fat: 3.91; protein 3.26; lactose 4.54 and total solids 11.93 %) and nitrogen excretion in urine (UrineNEXC, 102.4$\pm$95.1 $g.d^{-1}$), faecal (FaecalNEXC, 160.9$\pm$35.15 $g.d^{-1}$) and total N excretion (TotalNEXC, 248.6$\pm$93.04 $g.d^{-1}$). Predictive machines were developed using multiple linear regression (MLR), least absolute shrinkage and selection operator (LR), ridge regression (RR), random forest (RF), and artificial neural networks (ANN), mean absolute error (MAE), root mean square prediction error (RMSPE), Predictive ability (PA, coefficient of RMSPE/Mean of response variable), and predictive correlation (PC) were estimated using 5-fold cross-validation and used to compare predictive capability, and those machines with smaller values for PA and RMSPE were selected and ranked. Dry matter intake, body weight, and diet composition were the input variables selected in the ANN and RF methods with the best predictive performance as measured by PA and PC, lower than 0.2 and greater than 60% for all response variables, respectively (Table 1). The remote sensing and machine learning could be novel approaches for measurement, reporting and, verification in the improving the GHG national inventories, however, it is necessary to strengthen the measurements of nitrogen outputs to enhance the training process of predictive machines with higher performance that support the definition of local factors required to have better estimations on nitrogen excretion.

Table 1. Prediction models for total N excretion in dairy cows

Model/Method	Input variables*	Response variable	PC	RMSPE	MAE	PA
ANN	DMI+CP	TotalNEXC	0.91	38.43	27.31	0.15
ANN	DMI+DC	TotalNEXC	0.92	36.25	26.94	0.15
ANN	DMI+Forage+DC	TotalNEXC	0.91	38.42	28.11	0.15
RF	DMI+ CP	TotalNEXC	0.89	43.15	29.17	0.17
RF	DMI+BW+Forage+DC	FaecalNEXC	0.72	24.67	17.69	0.15
ANN	BW+NDF	FaecalNEXC	0.62	28.15	19.84	0.17
ANN	BW+EE	FaecalNEXC	0.64	28.04	20.84	0.17
RF	DMI+DC	FaecalNEXC	0.63	27.63	19.4	0.17
ANN	DMI+DC	UrineNEXC	0.99	16.87	11.8	0.14
ANN	BW+DC	UrineNEXC	0.98	18.31	13.24	0.15
ANN	BW+NDF+CP+Forage	UrineNEXC	0.98	19.87	13.66	0.16
ANN	DMI+Forage+DC	UrineNEXC	0.98	20.76	14.62	0.17

Keywords: machine learning, nitrogen excretion, carbon footprint, error prediction

A Stacked Ensemble Model Approach for Deriving Crops Phenology and Daily Agricultural Management Practices in Germany: Implications for Mitigation Measures on Greenhouse Gas Emissions

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Time-series crop management involves using detailed crop phenology information to enhance grain yield and quality by scheduling agricultural practices precisely. Monitoring the timing and intensity of management activities, such as fertiliser application, as well as crop growth stages, can provide valuable insights into agricultural systems' dynamics and environmental impacts. Process-based models, such as DNDC and MONICA, can simulate nutrient cycles, the movement of carbon in the soil, and greenhouse gas emissions. By using process-based models, we can evaluate the effects of various agricultural management practices on greenhouse gas emissions, soil organic carbon dynamics, and crop yields. However, applying these process-based models requires accurate daily input about crop management. Developing algorithms that automate the derivation of information on the timing and sequence of time series crop management could enable a comprehensive assessment of greenhouse gas emissions from different land uses.

The primary goal of this study is to develop an algorithm based on a stacked ensemble model for deriving management time series for Germany's croplands, specifically for the cropland sites of the German Agricultural Soil Inventory (BZE-LW) dataset covering the years 2001 to 2018. This algorithm primarily uses observed BBCH stages from the German Weather Service (DWD) and ground-based annual fertiliser application (nitrogen and organic) data. The study focuses on eight main crops cultivated in Germany during the specified period. This study describes its methodology in two main steps: (1) BBCH modelling and (2) crop management derivation.

(1) BBCH modelling: (i) Different combinations of features are extracted from seasonal observations. (ii) The "Boruta" algorithm then filters these features to select relevant ones, splitting the final DWD data into training (50%) and validation (50%) sets. (iii) During the classification steps, we optimise four different models using hyperparameters and cross-validation, and then combine them into a stacked random forest ensemble. (iv) We assess the performance of the five models using various measures, and determine the top-performing model by the Nash-Sutcliffe Efficiency (NSE) value. (v) At the BZE point, the best final model predicts the BBCH day of year.

(2) crop management derivation: recommended fertiliser distribution data establishes rules for determining fertiliser application timing and quantity. Based on the vegetation index's dynamics, we determined the missing BBCH stages.

We derived the spatial and temporal distribution of the phenological stages and agricultural management for each crop. The stacked model, random forests, and generalised linear model appeared to be the best most selected models. Our results indicate that remote sensing data have comparatively low explanatory potential compared to meteorological data for the development

of the eight crops. Accuracy assessments suggest low variance and good agreement for the modelled BBCH stages. However, the lack of ground data prevents the actual evaluation of the derived agricultural management time series. We will further discuss the implications of the results for modelled effects of mitigation measures on greenhouse gas emissions.

Keywords: crop phenology, agricultural management, stacked ensemble model, time series

Knowns and unknowns of the use of nitrogen transformation inhibitors

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Nitrogen transformation inhibitors, namely urease and nitrification inhibitors, are now increasingly used in agriculture to foster fertilizer nitrogen use efficiency and to reduce ammonia and nitrous oxide emissions from fertiliser application. Although there are several meta-studies demonstrating the emission reduction and nitrogen use efficacies (Abalos et al. 2014, Li et al. 2018, Fan et al.2022, Grados et al. 2022), the effectiveness of the use of inhibitors under various field conditions and over longer periods of time has not yet been sufficiently investigated. Several active ingredients already in practical use have only very limited coverage by scientific studies. For all substances, the long-term application of inhibitor active ingredients on the same field is an open question and whether and how soil microbes may adapt to this manipulation. This can have strong repercussion on emission factors attached to the use of nitrogen transformation inhibitors. Two German nation-wide projects ‘NH3min’ and ‘NitriKlim’, tackle these questions and shall provide new insights.

The risks of large-scale application of nitrogen transformation inhibitors for human health and the environment have not yet been fully investigated in the scientific literature. In addition, the data on the fate of the substances in the environment is incomplete and partly contradictory. These uncertainties are not fully mirrored in the registration procedures at EU and national level. In addition, the approval procedures are complicated and not very transparent, which makes it difficult for the public to understand inhibitors and connected environmental effects.

This paper aims to present existing knowledge gaps on the efficacies of nitrogen transformation inhibitors, highlight possible risks to the environment and health and shortcomings of the registration process.

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Keywords: N2O emission reduction, agronomy, NH3 emission reduction, nitrification inhibitors, environmental fate

Effect of nano-ZnO and ZnO on ruminal fermentation and methane production in sheep

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Enteric methane (CH4) emissions from ruminants represent one of the most important anthropogenic greenhouse gas sources, and it is a major issue regarding the impact of agriculture on climate change and the environment. Since agriculture contributes to approximately 18% of all greenhouse gas emissions decreasing these emissions represents one of the biggest challenges in ruminants' production systems. The primary factors affecting enteric methane emissions are feed intake, feed composition, and rumen microbiome. In ruminants, metabolism, performance, immunity, and health can be related to the provision of sufficient zinc, as zinc plays a catalytic, structural, and regulatory role for enzymes, proteins, and transcription factors. The ruminal microbiome is responsible for the dietary and metabolic needs of ruminants, which can be influenced by feed and mineral supplements. ZnO nanoparticles (nano-ZnO) are currently widely used as animal feed additives as well as antimicrobial and immunomodulatory agents. They are characterized by high bioavailability due to their small size and high surface-to-volume ratio. The objective of this experiment was to determine the effect of nano-ZnO and ZnO on ruminal fermentation, methane production, microbial population, and specific enzymatic activity after 70 days of supplementation in lambs. Twenty-eight lambs (Improved Valachian, 3-4 months of age, body weight of 18.8 ± 2.06 kg) were housed in common stalls with free access to water. Each animal was fed the experimental diet in four groups (n = 7/group): a diet composed of 350 g DM/day barley and 700 g DM/day meadow hay (Control), a diet enriched with nano-ZnO (40 mg Zn/kg of diet), a diet enriched with nano-ZnO (80 mg Zn/kg of diet) and diet enriched with ZnO (80 mg Zn/kg of diet). The experimental period lasted 70 days. Ruminal short-chain fatty acids were analyzed by gas chromatography and methane production was calculated from stoichiometric equations. *Eubacteria* and *Archaea* were quantified by real-time PCR. Ammonia-N concentration in the rumen was lower in the group enriched with 80 mg nano-ZnO than in other groups. Enzymatic activities determined by measuring the amount of reducing sugars released from the cell-free rumen homogenate showed higher cellulase ($P < 0.001$) and xylanase ($P = 0.002$) activities in all three experimental groups compared to the control. It can be concluded that the calculated methane production and the relative abundance of methanogens showed a tendency to a more significant decrease in sheep supplemented with nano-ZnO, which can probably support microbial metabolism without negative effects on rumen microbial fermentation.

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Keywords: zinc, nanoparticles, methane, fermentation, sheep

The effect of breed composition on methane efficiency in beef bulls

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Background: An effective way to reduce methane is to have the same or higher production (output) from more efficient animals. Producers in developed countries can use additive genetic variance to improve production efficiency linked to feeding behaviour related to access and intake of feed. These traits could be of interest as estimates for methane emission.

Aim: To estimate the methane efficiency and feed behaviour of different crossbred beef genotypes.

Methodologies: A crossbreeding experiment was carried out at the Vaalharts Research Station in South Africa, where indigenous Afrikaner, Bonsmara and Nguni cows were mated to Afrikaner, Bonsmara, Nguni, Angus and Simmentaler bulls in all possible combinations, rendering 15 beef genotypes. Weaning weights were adjusted by analysis of covariance to a constant Large Stock Unit. A Large Stock Unit has been shown to produce 94 kg of enteric methane per year. The mean Large Stock Unit in the dataset was 1.2335. Thus, methane efficiency was estimated by dividing least squares means for adjusted weaning weight by 116 (94 x 1.2335). Within each test group, the inter-day variance of feed for each animal were also ranked. The rank orders were subjected to Friedman's test wherein the significance of the breed group effect was tested using a chi-square statistic, calculated by multiplying the sum-of-squares for breed group by 12/((t*(t+1)) where t is the number of breed groups.

Results and discussion: The methane efficiency of purebred calves averaged 0.98 with an average heterosis of 3% (up to 16%). Crossbred calves produced by Angus and Afrikaner sires had the highest methane efficiency, while the Bonsmara was most efficient among the purebred calves. Breed group effects on feed intake were not detected ($P > 0.05$). However, growth rate differed significantly among the breed groups ($P = 0.01$). Partitioning the interaction of breed group with days on test into single degree of freedom effects revealed that only the effect of individual heterosis (0.99 ± 0.35 kg/day) was significant ($P < 0.01$). Afrikaner, Nguni, Angus and Simmentaler breed direct effects showed more inter-day variability in feed intake than the Bonsmara direct effect. These results indicate that the Bonsmara would not be as sensitive to the temporal environment in the feedlot compared to the other breeds.

Conclusion: Measurements of feeding behaviour and growth will significantly increase the amount of data for the genetic analysis for feed intake and methane production amongst crossbred cattle. Therefore, feeding behaviour traits are of prospective importance as estimates for feed efficiency and methane emissions. These results indicate that methane efficiency can be improved through utilizing crossbreeding.

Keywords: crossbreeding,beef, methane, heterosis, feed

Early-stage researcher mobility: Gender barriers and opportunities in capacity building for climate action

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Capacity building for climate action is critical to delivering the Paris Climate Change Agreement and realizing impact from the UNFCCC climate negotiations. Article 11.1 of the Paris Agreement indicates that capacity building should enhance the capacity and ability of developing country Parties to implement adaptation and mitigation actions. Assessments of the geographic distribution of IPCC authors reveal an asymmetry and skew towards IPCC authors from the global North, mostly men, with underrepresentation of climate experts from developing countries, particularly least developed countries and especially women. A key challenge for capacity building and professional development for climate action is to ensure socially inclusive education and training that fosters equality of both opportunity and outcome, particularly for cohorts who are marginalized. This is also critical to delivering on the aspirations of the 2030 Agenda for Action to “Leave No One Behind”.

The importance of agrifood systems to society and economies in developing countries is challenged by the need to transition to climate-smart agrifood systems i.e., with low emissions and resilient to climate change. A focus on training the next generation of climate change professionals from developing countries is essential. CLIFF-GRADS is a training program that was established to build capability of early career researchers from low- and middle-income countries to conduct applied research in agriculture greenhouse gas emission quantification and mitigation. During short research stays of up to 6 months with a destination host institute, CLIFF-GRADS awardees are exposed to expertise and scientific training that they would not otherwise receive during their PhD program.

Current assessments of the CLIFF-GRADS program indicate that women are not only under-represented, but also are not applying for the program as frequently as men. To address these challenges, we are implementing a study to support climate-change capacity building programs to better understand, reflect on, and challenge gender norms and roles affecting young women and men, which may limit their ability to engage in climate action training programs or derive the most benefit and impact from such opportunities. We contribute to the literature on how gender roles and gender equality affect outcomes, via their interaction with entities outside the household; and the growing literature on climate change and agency, including how young women, when given opportunities, can play a strong role in climate change mitigation.

Using the CLIFF-GRADS program as a case study, we focus our analysis on three crucial stages: (1) the application process, where we focus on understanding barriers to get accepted into the capacity building program; (2) the training period, where we analyze constraints and benefits derived from the program; and (3) outcomes, focusing on challenges to applying the acquired knowledge in their work and contributing to climate action in their own countries and globally. We are conducting a survey to collect primary data from CLIFF-GRADS applicants (n=873) and their research supervisors and will present preliminary findings from the study.

Keywords: gender inclusion, capacity building, climate action, research mobility

Farmgate methane intensity of beef can be reduced by changes in cow-calf efficiency traits

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Background: A simulation programme was used to estimate the farm-gate methane intensity ($kgCH_4$/kg live weight leaving the farm) of 9 major beef breeds in South Africa. This simulation indicated a difference of up to 44% in the methane intensity between breeds. Breeds with the lowest methane intensity were the Afrikaner (0.60), Bonsmara (0.59), Angus (0.59), Brahman (0.61), and Brangus (0.62).

Aim: The component traits used were cow weight, calving percentage (estimated from inter-calving period (ICP)), and calf weaning weight. This study evaluated the impact of a 10% alteration in each component traits on the methane intensity.

Methodologies: The breeds included in the current study were Afrikaner (small frame), Bonsmara (medium frame) and Simmentaler (large frame). Each of the component traits was changed by 10%, while the others were kept constant. A farm size of 1200 hectares, with a carrying capacity of 6 hectares per Large Stock Unit (LSU) that carry 200 LSU's, was used in the simulation. Frame size specific equations were used to estimate cow LSU units. The Tier 2 Intergovernmental Panel on Climate Change (IPCC) approach indicated that the enteric methane emissions factor of an LSU was equal to 94kg methane/year. The methane intensity was therefore estimated as 94kg methane x 200 LSU's (18 800kg methane) divided by the kg live weight leaving the farm (weaner calves and culled cows).

Results & Discussion:

Frame size did not affect the changes that occurred in the methane intensity when the component traits were changed by 10%. A 10% increase in calf weaning weight had the largest positive effect (lower methane intensity), where the kgCH4/kg live weight decreased by 6.8%. Surprisingly fertility, as measured by the ICP, had a small effect (-1.7%) on the methane intensity. Normally fertility is having the biggest effect of cow-calf efficiency, but is not the case when a reduction in carbon footprint is considered. A decrease of 10% in cow weight resulted in an increase in the methane intensity (+3.1%), which was at first surprising. However, it should be noted that if cow weight decreases, the kg of live weight from the culled cows leaving the farm is also less.

Conclusion & Recommendations:

The findings of this study provide valuable insights into estimating changes in the farm-gate methane intensities for different breed types, production levels, and systems. It is recommended that a carbon footprint index is developed that includes the three component traits. Such indices will be valuable in the era of climate change, especially since that implementation of carbon taxation measures may be due in the near future. The same approach can be used to estimate changes in the farm-gate blue water footprint of beef production.

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Keywords: breed type, carbon footprint index, cow weight, fertility, weaning weight

Nitrification inhibitors as climate mitigation measure in German crop production?

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Agriculture is responsible for c. 80% of all nitrous oxide (N_2O) emissions in Germany, mainly resulting from soil processes after application of nitrogen-containing fertilizers. Emissions might be reduced by using nitrification inhibitors. For a reliable recommendation of inhibitors as a climate protection measure however, some open questions have to be clarified:

- Are the available inhibitors equally effective in reducing N_2O emissions at different sites in Germany?
- Are reduction effects still relevant, when N_2O emissions are evaluated on an annual basis or will there be an offset?
- Will repeated application of inhibitors result in long-term effects on the soil and will this affect the effectiveness of newly applied inhibitors?
- What effects are to be expected on nitrate leaching and associated indirect N_2O emissions?
- What are the effects of nitrification inhibitors on yield, quality, fertilizer management and the economy of crop production? What is the level of acceptance among farmers?
- What are potential negative environmental effects, in particular on soil microbial communities, on compound leaching to ground waters or on ammonia and methane emissions?

To address these questions a country-wide network of coordinated field and laboratory experiments is performed. All nitrification inhibitors available on the German market are evaluated in combination with mineral and organic nitrogen fertilizers. Measurements cover greenhouse gas and ammonia emissions, nitrate and inhibitor leaching, as well as inhibitor effects on nitrification and the microbial community for short-term and long-term inhibitor application.

Finally, a comprehensive assessment of the use of nitrification inhibitors as a climate protection measure will be carried out. Preliminary results from the ongoing project that started in 2023 will be presented.

Keywords: nitrification inhibitor, N2O emission, arable crop production

The effect of timing of grass renewal on the GHG exchange on a drained organic soil

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Organic soils cover about 10 % of Finland's arable land but are responsible of 50-60 % of the total greenhouse gas (GHG: CO_2, CH_4 and N_2O) emissions from the agricultural sector. The GHG emissions from drained organic soils can be reduced by grass cultivation and minimal tillage. Traditionally, fields are ploughed in autumn leaving the field bare until new grass is sown in the following spring. During this overwintering time, the GHG emissions are usually higher compared to a vegetated field. To overcome the adverse impact of the long fallow period and consequently to lower GHG emissions, the grass can be renewed in summer after the first harvest. This could also enable a second harvest in the autumn from the cover crop as a whole crop silage. Is summer ploughing on agricultural peat soils a sustainable practice? Research aiming to provide answers to such question is needed to support the political decision making to reach Finland's carbon neutrality goal by year 2035 and to generate climate-smart agricultural practices.

With this in view, we conducted a three-year study on a grassland on peat soil field in eastern Finland. The experimental plots had two treatments: autumn ploughing with spring renewal and summer ploughing with summer renewal. From May 2021 to May 2023, we measured the emissions of all three GHGs (CO_2, CH_4 and N_2O) with closed chamber technique during snow free period and snow gradient method during winter. Simultaneously, the GHG exchange from the whole 6 ha field with summer renewal practice was measured with the Eddy Covariance technique for two full years in 2022 and 2023. This presentation describes the effect of timing of ploughing and grass renewal on the GHG exchange in this grassland on the drained peat soil.

Keywords: drained organic cultivated soils, climate-smart agriculture, greenhouse gas fluxes, climate change

Monitoring GHG exchange from dairy grasslands on different soil types in Finland

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Grasslands are a key component of boreal agriculture and can play a significant role in soil carbon sequestration and mitigation. Finland, located in the boreal climate zone, is known for its milk production with one of the highest per cow milk yields in Europe. Milk production in Finland relies heavily on grassland management. The growing season is short and varies from 105 days in the north to 185 days in the south. Finnish grasslands are managed on two types of soils: mineral soils and organic soils. Mineral soils are typically well-drained and have a low organic matter content, whereas organic soils are characterized by high organic matter content and high-water retention capacity. With a view to understanding the sustainability of grassland production on different soil types in Finland, we have initiated a long-term GHG monitoring framework for a sustainable grassland management and agriculture at the Natural Resources Institute Finland (Luke) across several agricultural research sites in Finland. The results presented in this study will shed light on the variability of GHG-fluxes from grasslands on different soil types and on the key drivers of the temporal and site variability of GHG-fluxes in a comparative way.

The whole ecosystem scale measurements of GHG fluxes made using the eddy covariance technique are direct and continuous. These data provide a detailed insight into the annual variability of GHG exchange, but also shed light on day to day inter- and intra-seasonal (short – term) changes in ecosystem behavior owing to changing climatic conditions, farm management operations carried out on the farm and to the natural phenological crop growth. Such data measured across years and research/farmer sites will serve as decision criteria for a sustainable production of food and fodder.

Keywords: climate change, greenhouse gas exchange, Boreal agriculture, Eddy covariance technique, drained organic soils

The role of fresh and ensiled Rugosa rose (*Rosa rugosa Thunb*.) pulp in *in vitro* modulation of basic ruminal parameters in dairy cows

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There is a growing expectation for a significant reduction in global methane emissions. One of the key restrictions has been placed on animal production where the development of robust mitigation strategies is attracting special attention. Nowadays, the increasing pressure to establish sustainable agriculture coincides with the optimization of livestock feed for enhancing milk yield and minimizing environmental impact. Dietary industrial by-products rich in bioactive natural components (BAC) have a great potential to support more sustainable production by reducing methane emissions from ruminants. The study aims to investigate whether fresh (RFPF) and ensiled Rugosa rose (RFPS) pulp affects the basic ruminal parameters in dairy cows *in vitro*. The control group (CON) comprised grass silage whose chemical composition is very close to that of RFPS.

Basic ruminal parameters (pH, ammonia, VFA) were determined in buffered ruminal fluid incubated in a batch culture system. The preliminary chemical composition of RFPF (n=4) and RFPS (n=4) was analyzed by the AOAC methods (2007). The fatty acids (FA) profile of incubated rumen fluid was analyzed by gas chromatography. The neutral detergent fibre (NDF) was determined according to Van Soest et al. (1991). The quantitative analysis of the phytochemical metabolome was done by the Folin-Ciocalteau (F-C) method whereas qualitative identification of main compounds by liquid chromatography (LC) coupled with mass spectrometry (ESI)-QTOF-MS. The total gas production, CH_4 production, and ruminal fermentation characteristics were determined using the Hohenheim gas test technique.

The research showed that both RFPF and RFPS are valuable sources of basic chemical compounds (eg. crude protein content was 158 and 161 g/kg DM, respectively) as well as unsaturated fatty acids (e.g. C18:3 n-3: 29.13 g/100g FA and 29.56 g/100 g FA, respectively). A high concentration of total polyphenols (gallic acid equivalent) was observed in RFPF (465 mg/100 g DM) and RFPS (509 mg/100 g DM). We demonstrated that regardless of the form applied, Rugosa rose pulp affects basic rumen parameters, methane production, and FA profile. Although RFPF and RFPS contained seeds, grass silage (CON) had better digestibility after 24-hour incubation. Ultimately, methane was decreased in RFPF or RFPS groups (both CH_4 mmol/g DM and CH_4/IVDMD ($mM \cdot g^{-1}$). Changes in the ratio of acetic to propionic acid were also observed.

The preliminary results demonstrate the potential of RFPF or RFPS to reduce methane production and to change the FA profile in a pro-health mode.

Keywords: by-products, methane production, bioactive natural components

GHG emissions under the use of fertilizers and inhibitors in a maize agroecosystem

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Soil carbon and nitrogen have dragged much attention over the last years due to their crucial roles in crop production and their impacts on environment quality and/or global climate change. Since fertilization remarkably changed the C and N cycles, various mitigation and/or adaptation strategies, including the application of farmyard manure (FYM) and/or urease and nitrification inhibitors (UI and NI) have been developed.

The aim of this study was to assess the influence of mineral and organic fertilization with and without urease and nitrification inhibitors on the CO_2, CH_4, and N_2O emissions in a maize agroecosystem.

The experiment scheme included the following treatments: C (the control without fertilization), UAN (Urea Ammonium Nitrate), UAN+UI, UAN+NI, UAN+UI+NI, FYM with N mineral fertilizer, FYM with N mineral fertilizer +UI, FYM with N mineral fertilizer +NI, and FYM with N mineral fertilizer +UI+NI.

The results indicated that nitrification and urease inhibitors were effective in reducing N_2O emissions. Using mineral and organic fertilization, along with nitrification and urease inhibitors, caused significant changes in carbon and nitrogen compounds in the maize agroecosystem. The most notable differences were seen in the nitrogen pool with mineral fertilization and inhibitor use. Under organic fertilization, the effects of inhibitors were weaker, potentially due to their adsorption, faster degradation, and reduced effectiveness at higher SOC contents. Soil properties were positively correlated with CO_2 and N_2O effluxes, indicating their contribution to the processes of soil respiration, nitrification, and denitrification.

Keywords: CO2, CH4, and N2O emissions, organic and mineral fertilization, urease inhibitor,nitrification inhibitor, soil properties

Greenhouse Gas (GHG) emissions from soilless crops in urban agriculture in tropical climate

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Cities are most vulnerable to food supply disruptions due to high dependency on imports, evidenced by the Covid-19 Pandemic and Suez Canal Crisis. The situation is expected to worsen due to the negative impact of climate change. Urban Agriculture (UA) is increasingly recognised as a contributor to food security in cities as it enables local food production in disused spaces e.g. rooftop and warehouses, without expanding into natural areas. With rising population and urbanisation, UA will become more prevalent in cities as the demand for food will increase. Significant increase in food production can increase greenhouse gas (GHG) emissions. The Paris Agreement aims to limit global temperature increase to no more than 1.5°C, above pre-industrial levels, which requires reduction of global GHG emissions by halve by 2030 and reach 'net-zero' by 2050. UA with low GHG emissions becomes necessary to reduce the effects on climate change, so it's critically important that we are able to measure GHG emissions from UA accurately. There are many forms of UA e.g. soil-based culture and soilless culture such as hydroponics where plants grow within a controlled environment to optimise horticultural practices. Emission Factors (EFs) for soil-based cultivation are well established, however, at present, there is a lack of studies that determine the generation of GHG emissions from soilless crops to account for their global warming potential, particularly in the tropics, and there is no methodology established for sampling of GHG emissions from recirculating water culture (hydroponics). EFs for soil crops are commonly used in Life Cycle Assessment studies on UA soilless crops due to lack of data. There is a need for more studies to obtain precise data on direct emissions, particularly for soilless crops. This research aims to propose a customised flow-through gas chamber to quantify GHG emissions from lettuce crops grown in nutrient film technique (NFT) in greenhouse and indoor space in Singapore. Preliminary findings showed that EF measured for soilless (NFT) lettuce crop cultivated in indoor space range about 0.0024 - 0.0037 kg N_2O per kg N, which was less than half the EF of the IPCC method (0.0125 kg N_2O per kg N) for soil crops. The research is still on-going. Overall objective of this study is to contribute knowledge to the development of more appropriate EF of soilless crops grown in greenhouse and indoor spaces in tropical climate.

Keywords: soilless crops, flow-through chamber, tropical climate

Cost-Effectiveness of Peatland Restoration: A Novel Approach to Construction of Marginal Abatement Cost Curves

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Peatlands cover approximately 3% of earth's surface but store up to a third of all organic carbon. Healthy peat bogs are a natural carbon sink, but as much of these valuable ecosystems are degraded due to human activities linked to agriculture, development and industrial extraction, they become a prominent source of GHG emissions. Restoring peatlands back to their (near) natural conditions is thus becoming both a necessary action to address the climate emergency and a political priority. The restoration efforts are often complex projects consisting of several phases and require application of a combination of measures that bring on substantial implementation, opportunity, and maintenance costs. Understanding the distribution and drivers of variation in these costs is critical in determining the feasibility and appropriateness of future restoration efforts. The marginal abatement cost curves (MACC) are frequently used in both academic research and industry to produce an applicable cost-effectiveness rank of available and relevant abatement measures in context of their total abatement potential. These data-intensive, technologically rich models serve as a practical guideline for policymaking aimed at maximizing value for money. In the case of peatland restoration, a set of site-specific environmental, economic, and technical conditions drive the choice, total cost and total abatement potential of selected measures. Unlike with the industry standard MACCs, in the case of peatland restoration the applied measures need to work in accord in order to deliver the desired results. For this reason, a novel method to constructing a MACC is developed here with a focus on the underlaying conditions that drive the variation of restoration costs. A comprehensive database of accomplished restoration projects dating back to 2016 is analyzed, and expanded with a broad set of environmental and spatial variables. Using a clustering algorithm, a set of condition clusters was produced and cost-effectiveness value (in terms of cost per unit abated) was calculated. Further, a spatial model for determining the allocation of all degraded peatland into the condition clusters was applied. The results show a distribution of both costs and abatement potentials for all the peatland in each cluster and thus allow for scenario modelling of future potential restoration pathways with focus on the most cost-effective avenues for scaling up of such efforts in order to achieve the given GHG emission reduction targets.

Keywords: marginal abatement cost curves, cost-effectiveness, peatlands restoration, economic modelling, condition clusters

The Flemish Centre of Expertise for Agriculture and Climate (ELK) – A multidisciplinary knowledge hub for climate-related agricultural research

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The ILVO Centre of Expertise for Agriculture & Climate (ELK), established in 2016 under the auspices of the former Flemish Minister of Agriculture, supports and advices agricultural and environmental policy makers and the broader agricultural sector on climate-related topics. ELK consolidates the multidisciplinary climate knowledge within ILVO, identifies knowledge gaps, and induces new research. It closely monitors international developments in agricultural and climate research, placing the Flemish context in a Belgian, a European and a global perspective.

The ELK's research themes are focussed on two main pillars: reducing the impact of Flemish agriculture on climate change (mitigation) and enabling agriculture to adapt to climate change (adaptation). Adopting a systemic approach, ELK considers broader sustainability aspects of the agri-food chain, encompassing societal, economic, and environmental factors.

As an expression of ELK's multidisciplinary approach, a 'systems thinking' exercise has been performed. This exercise involved experts from diverse research areas collaborating to understand the complex interplay between climate mitigation, climate adaptation, and carbon storage, in an agricultural context. This framework is essential to assess whether climate measures are genuinely climate-smart, avoiding solutions that achieve one goal but impede others.

The ELK systems thinking exercise delves into various key subsystems essential for understanding agricultural and climate issues, and is centred around the farmer's choices, examining the relationship among different emission sources (such as enteric emissions from livestock, energy consumption, soil emissions,…). By elucidating this intricate web of connections, we gain insight in climate mitigation and adaptation factors, transcending individual research themes.

Keywords: climate, systemic, multi-disciplinary, mitigation, adaptation

Investigations on the relationship between locomotion score and methane emissions of cows

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A live cycle assessment study simulating methane emissions in lame dairy cows suggest that lameness increases the environmental impact on farm level (Chen et. al.; 2016). However, studies on the direct influence of lameness on methane emissions from dairy cows are scarce. To investigate the relationship of lameness and methane emissions in dairy cows, a data set with different degrees of spontaneously occurring lamenesses and methane emission data from German Holstein dairy cows was analyzed. In total data from forty-eight dairy cows were available. The cows were kept in a free stall barn with slatted floor and high stalls covered with rubber mattresses. The animals received a partial mixed ration (PMR) as a basal diet. Water and the PMR, which contained 13.5% concentrate on a dry matter (DM) basis and was prepared daily with a feed mixer wagon (TrailedLine Premium 9, Siloking Mayer Maschinenbau GmbH, Tittmoning, Germany), were offered *ad libitum* via weighing troughs (Insentec B.V., Marknesse, Netherlands). The PMR was complemented by concentrate via automated concentrate feeding stations (Insentec B.V., Marknesse, Netherlands). The feeding period lasts 18 weeks and was divided into 3 rounds with a length of six weeks. The basic design consisted of two concentrate proportions (30 and 55% in relation to the DM of the total ration) and a varying composition of the individual feed components. The different feed composition in the three rounds was achieved by feeding varying proportions of soya oil (fat, round 1), the administration of a phytogenic substance (oregano, round 2) and varying proportions of hay (hay, round 3). The fat and oregano components were administered via the concentrate and the hay component via the PMR. The Greenfeed system (C-Lock Inc., Rapid City, SD, USA) was used to quantify daily and animal individual methane emissions. During the whole trial, the locomotion score was determined weekly according to Flower & Weary (2006). Retrospectively, the animals were assigned to one of four groups according to their locomotion score; healthy cows, slightly lame cows, lame cows and clearly lame cows. Starting from a slight lameness, the cows begin to show comparatively higher methane emissions to healthy cows. Measurements show that the locomotion score has a significant impact on methane production intensity and yield. Under the existing husbandry conditions of the present study, an association between lameness and methane emissions was demonstrated. Further studies with larger data sets are needed to confirm and quantify this relationship.

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Keywords: Holstein dairy cows, lameness, methane emissions

Revised Tier 2 Protocol for Enteric Methane Emissions from African Small Ruminants

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Accurate monitoring of greenhouse gas (GHG) emissions is fundamental for the advancement of mitigation strategies in African small ruminant production systems. This protocol outlines the Intergovernmental Panel on Climate Change's (IPCC) Tier 2 methodology approach tailored for generating region-specific enteric methane (CH_4) emission factors (EFs = CH_4 kg/head/year) for small ruminant production systems, primarily sheep and goats in Africa, which is home to more than 40% of the world's small ruminant population. The Tier 2 approach, by integrating locally measured specific animal activity and dietary data, enables more accurate accounting of national greenhouse gas (GHG) inventories and the crafting of mitigation strategies that resonate well with the agronomic and climatic realities of Sub-Saharan Africa. Tier 2 is a step forward from the broadly applied Tier 1 approach, which often leads to over-generalized results due to its reliance on continental-level activity data. The protocol is developed in compliance with the Paris Climate Change Agreement, under which member states have pledged to regularly report their national GHG inventories and devise context-appropriate mitigation strategies. The motivation for this protocol is to equip researchers and policymakers with a robust framework for collecting data and calculating improved EFs for small ruminants in Sub-Saharan Africa. In this protocol, year-long data collection at farm level includes household selection, seasonal measurement of animal production and changes in feed quality and availability. Collection of samples for analyses and other relevant data are described. Step by step calculation of net energy expenditure and subsequently daily CH_4 production using equations from the updated IPCC guidelines is described. By employing the Tier 2 approach, this protocol aims to bridge the gap between the default EFs and the nuanced dynamics of feed intake, quality, and animal metabolism in diverse African environments. This protocol is relevant for smallholder mixed crop-livestock systems and the pastoral systems that are prevalent in Sub-Saharan Africa, as well as other small ruminant-rearing frameworks. This ensures that diverse production systems, each with their distinct management practices and environmental challenges, can estimate their emissions and mitigation actions. The relevance of this protocol is multi-faceted: it serves as a critical tool for enhancing the accuracy of GHG monitoring at farm level, offering a refined perspective on the environmental impacts of small ruminant husbandry. Furthermore, it empowers stakeholders across the agricultural spectrum—from researchers connecting feed characteristics with animal performance, to farmers optimizing nutrient utilization, and to policymakers strategizing for sustainable development. By providing a detailed and scientifically robust approach, this protocol is positioned to play a pivotal role in aligning local agricultural practices with global environmental objectives. It supports the advancement of sustainable small ruminant farming in Sub-Saharan Africa, fostering climate-resilient livestock systems, and contributing to the overarching goals of GHG reduction and environmental stewardship.

Keywords: methane emissions, small Ruminants, Tier 2 Protocol, Sub-Saharan Africa, GHG monitoring

Taurine inhibits the nitrous oxide in soil through modifying bacterial community

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Nitrous oxide (N_2O) is a potent greenhouse gas and the main factor that depletes the ozone layer of the atmosphere [1]. In animal industry, N_2O is mainly produced in the storage of excreta and in the use of excreta as fertilizer in the soil [2]. Dietary supplementation with taurine increased the urinary excretion of taurine in beef cattle [3]. Yet it is not known whether urinary taurine affects the N_2O emissions. The objectives of the experiment were to investigate the effects of taurine on the N_2O emissions from the soil applied with artificial urine [4] using static incubation technique [5].

Five levels of taurine, i.e. 0.00, 1.00, 2.00, 4.00 and 8.00 mmol/L were composited in artificial urine as treatments. Each treatment included 6 replicates. The incubation lasted 15 days. Adding taurine linearly decreased the N_2O-N ($P < 0.001$) fluxes and the average concentrations of NH_4^+ ($P < 0.001$) and NO_2^- ($P < 0.001$), whereas quadratically increased the average concentration of NO_3^- ($P = 0.010$) of the soil applied with artificial urine during the incubation period. At the phylum level, adding taurine at 4.00 mmol/L linearly decreased the relative abundance of *Actinobacteriota* ($P = 0.042$) and at 4.00 and 8.00 mmol/L linearly decreased the relative abundance of *Bacteroidota* ($P < 0.001$), increased the relative abundance of *Firmicutes* ($P < 0.001$) and the relative abundances of *Methylomirabilota* ($P = 0.002$). At the genus level, adding taurine linearly increased the relative abundances of *Bacillus* ($P < 0.001$) and *Pseudomonas* ($P = 0.035$). By analyzing the abundance of taxonomic groups at the genus level involved in the nitrogen (N) transformation in the soil, adding taurine linearly increased the relative abundances of total N-fixing bacteria ($P < 0.001$), total nitrifying bacteria ($P < 0.001$) and denitrifying bacteria ($P < 0.001$). By analyzing the relative abundance of functional modules related to soil bacteria of N transformation, adding taurine linearly increased the relative abundances of nitrification ($P < 0.001$) and linearly decreased dissimilatory nitrate reduction ($P < 0.001$).

Taurine decreased the N_2O-N emissions through enriching the bacterial community and improving the nitrification process in soil. Adding taurine at 1.00, 2.00, 4.00 and 8.00 mmol/L decreased the N_2O-N fluxes by 53.77%, 67.8%. 71.2% and 78.1%, respectively. Field experiments are necessary to verify the effects of taurine on the N_2O-N emissions of animal urine.

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Keywords: bacterial community, nitrification, nitrous oxide, soil, taurine

How do we get the farm-level touchdown of re-duction pathways right? Quantification, a common vision and communication

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Tackling climate change poses challenges to society and demands profound changes from today's business as usual system – also in agriculture (*Rockström, J., Edenhofer,O. et al. 2020, https://doi.org/10.1038/s43016-019-0010-4*). In the pilot project „Climate neutral agriculture Graubünden" running between 2020-2025 (www.klimabauern.ch) 52 farms started experimenting on their farms to move towards a climate neutral agricultural system with the ambitious goal to take along the remaining 2000 farms of the canton by 2050.

A farm level greenhouse gas inventory of each of the 52 farms at the beginning of the project (*Huber, S., Baumann, F. et al. 2022, „Treibhausgase aus der Bündner Landwirtschaft"*) unraveled the challenges of such a transition, more so in this mountainous area with large grassland areas used for ruminants. Nevertheless, the farm-level inventory highlighted starting points of feasible reductions at the farm level, allowing farmers to implement targeted measures on their farms. The ex-post monitoring, i.e. the quantification of achieved reductions is yet another challenge, where our results show that particularly farm level GHG-inventories have limitations for this purpose – but also measurements are rarely feasible or costly.

A cantonal inventory, which includes all farms and is based on census data might be another option to monitor progress on a system level. We present the cantonal inventory along with the assessment of the reduction potentials of various technical and structural reduction measures which results in possible pathways towards the goal of a climate friendly agriculture and allows a more realistic and concrete definition of goals on a system level.

Finally, as the farmers are key actors for the touchdown of reduction measures at the farm-level, aligning the technical reduction potentials with their vision of a climate neutral agriculture is key to establish ownership of the foreseen changes. A survey with the pilot farmers and additional farmers from the canton underlined the pioneer character of the pilot farmers, but also highlighted the involvement and awareness of the additional farmers about the topic of climate change. Furthermore, the survey addressed socioeconomic and cultural factors such as farmers identity, networks or advisory services, and how they might hinder or promote the transition. The survey, along with group discussions among the pilot farmers will help to establish a common vision, which will inform the development of the project past the pilot phase.

We present an overview of these diverse aspects on the basis of our case study to exchange on possible ways forward for the "farm-level touchdown of reduction pathways".

Keywords: farm-level emissions, GHG calculators, reduction pathways, common vision, socio-economic and cultural factors

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