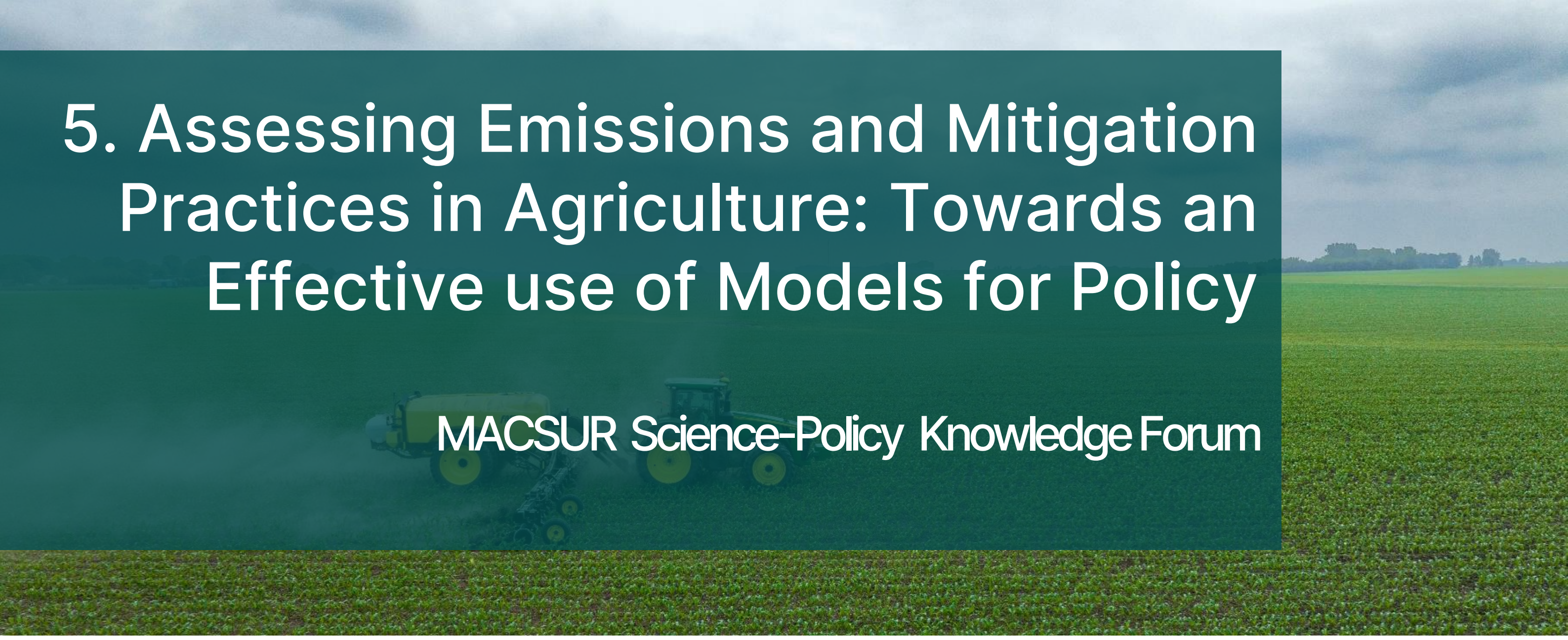

5. Assessing Emissions and Mitigation Practices in Agriculture: Towards an Effective use of Models for Policy

MACSUR Science-Policy Knowledge Forum

The policy brief presents the application of ensembles of agricultural models in assessing emissions and mitigation practices.

Key Messages

- Model ensembles perform better than a single model for estimating emissions and assessing mitigation practices.
- The median value of a minimum set of ~10 models can reduce the error below acceptable thresholds
- Minimal calibration with plant measurements substantiates the ensemble estimates and reduces uncertainties
- The effectiveness of a biogeochemical modelling framework calls for its integration into operational frameworks to support policy decision making

Relevance

In order to enhance climate policy making in agriculture, an ensemble of biogeochemical simulation (crop and grassland) models of agricultural systems can be used for ‘demand-driven’ research for use by decision-makers. The aim of this brief is to provide an overview of modelling capabilities to help frame a debate on the relevant policy issues that biogeochemical models should address, i.e.

1. whether and to what extent an ensemble of models performs better than single models;
2. the minimum ensemble size;
3. the set of data required to substantiate ensemble estimates.

Based on thorough assessments of model ensembles for the simulation of C-N fluxes and stocks at a variety of agricultural sites worldwide, policy making can effectively achieve agro-environmental targets and help farmers cope with a range of emerging challenges such as food security in the context of global environmental and economic changes.

Benefits of biogeochemical modelling

Simulation models provide a testing ground for agricultural policy decisions within structured frameworks. The benefit they bring is a deeper understanding of agricultural systems and better-informed policy implementation. This is relevant today, as agricultural policies are likely to affect multiple social and ecological aspects such as the reduction of CO_2 emissions and the conservation of ecosystem services. Biogeochemical processes (e.g. nitrogen and carbon cycling) are central to agricultural planning and nutritional assessment and have become a sustained research topic. Closely linked to terms such as "climate-smart agriculture", "low-carbon agriculture" and “GHG-mitigating farming practices”, biogeochemistry cuts across knowledge from life, agricultural, food and medical sciences. As governments and societies now jointly take important decisions that are expected to structurally change the shape of economies in the coming decades (e.g. on the road to decarbonisation), biogeochemical models should look and work ahead to support agricultural policies.

How do models work?

Focusing on the chemical elements and ecological relationships among agricultural organisms (mainly plants and animals), simulation models describe and quantify the contribution of agricultural systems to C sequestration and GHG source/sink status through mathematical equations that represent biogeochemical processes. Perhaps the best example of biogeochemical modelling is the balance between photosynthesis (C uptake) and respiration (C source). However, models also include organic matter decomposition, fermentation, ammonia volatilisation, nitrification and denitrification, underlying transformations and transport of water, C and N in plant-soil systems, so that changes in environmental and management factors collectively affect a set of biogeochemical reactions. Nitrous oxide, carbon dioxide and methane are known to contribute to a net increase of GHGs in agroecosystems.

Evaluating the impact of agriculture on climate warming thus requires the ability to estimate net exchanges of these gases using systemic modelling approaches that respond to environmental conditions and agricultural management. Simulation tools abound and predictions from different biogeochemical models show high variability and uncertainty, as each model (with its own strengths and weaknesses) is a unique (simplified) representation of the agricultural system made of interacting soil, plant and atmospheric processes and farming practices. The use of biogeochemical models to assess C and N balances in agricultural systems facilitates decision making to support policies.

What have biogeochemical model ensembles done?

Widely tested biogeochemical models (with coupled C-N cycles) have proven to be effective tools for examining the spatiotemporal patterns of C and N fluxes and stocks and can play an important role in designing specific policies on environmental and sustainability issues, tailored to the soil, climatic and management conditions of a site or region. They may include promoting practices to enhance soil C sequestration and reduce N leaching while reducing potential trade-offs between agricultural productivity and the provision of ecosystem services. An ensemble of models performs better than single models, the median values of the data simulated from different models perform better and provide a more comprehensive insight that would not be possible with any individual model. Multiple international model inter-comparison exercises have shown the potential of process-based model ensembles to jointly estimate agricultural productivity and C and N emissions (and stocks). Many have been coordinated by the Agricultural Model Intercomparison and Improvement Project and the Integrative Research Group of the Global Research Alliance on agricultural GHGs, and supported by research projects financed by national funding agencies. These studies have provided support for a ground to estimate C storage and proved effective in assessing the effect of low-intensity grazing and reduced N fertilisation, as well as replacing N fertilisers with symbiotically fixed N in reducing agricultural emissions.

These findings question the use of model ensembles for upscaling projections of agricultural productivity and C-N emissions from field scale to larger spatial units as needed for Tier 3 national inventories. Beyond the evidence that ensembles of models perform better than individual models (with the multi-model median of model outputs used as a descriptor of the ensemble performance), inter-comparison studies have provided information on the minimum ensemble sizes (e.g. ~10 models for crop productivity) and datasets (some plant measurements as calibration data) required to substantiate ensemble estimates. From a policy perspective, this is critical for the implementation of model ensembles to identify the extent to which management interventions influence C-N fluxes and stocks (e.g. C emitted per unit of marketable production) before promoting food security and climate policies that alter agricultural practices to meet prescribed benchmarks.

Prospects for policy implementation

Agricultural (crop and grassland) biogeochemical models are now used to address broader issues than agricultural production. The evidence of what can reasonably be expected from the use of an ensemble of biogeochemical models in agriculture aims at guiding agro-environmental C- and N-smart policies, designed and adapted to farms and territories. This calls for the integration of biogeochemical modelling into operational, multi-model decision-support frameworks to investigate the effects of alternative farming practices through changing a range of assumptions (e.g. on fertilisation or grazing pressure) and observing how the model ensemble responds, in terms of C and N fluxes and stocks (beyond agricultural production). This has potential benefits and policy implications for supporting sustainable intensification and fostering sustainability and innovation through improvements in fertiliser and water use, redistribution and recycling of nutrients, implementation of climate-smart options including changes in crop and grassland management, and enhancement of biodiversity within farming systems. While rural service centres can appropriate models and the ensemble methodology to support policies at the local level, targeted support from the European Commission's Joint Research Centre could translate into policy implementation at the EU level.

Further Reading:

Farina, Roberta, Renata Sándor, Mohamed Abdalla, Jorge Álvaro-Fuentes, Luca Bechini, Martin A. Bolinder, Lorenzo Brilli et al. Ensemble modelling, uncertainty and robust predictions of organic carbon in long-term bare-fallow soils. Global Change Biology 27, no. 4 (2021): 904-928. https://doi.org/10.1111/gcb.15441

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The MACSUR SciPol knowledge forum is a pilot exercise initiated by the Joint Programming Initiative for Agriculture, Food Security and Climate Change (FACCE-JPI) to bring science and policy actors together for the strategic design of climate change adaptation and mitigation solutions in the agri-food sector in Europe. This policy brief contributes to this mission by providing evidence-based information to policy for achieving carbon neutrality by 2050, adapting to climate change and understanding synergies and trade-offs in achieving these targets.

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