THÜNEN

Project *brief*

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Modelling of natural and management-related effects on nitrous oxide emissions from crop rotations of raw material plants (THG EMOBA)

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- **Land use-related nitrous oxide emissions are relevant greenhouse gas (GHG) emissions in crop rotations of renewable raw materials (NAWARO) and must be quantified for the evaluation of GHG saving potentials of bioenergy lines**
- **We tested biogeochemical and stochastic modelling approaches developed for the quantification of land-use related nitrous oxide emissions on extensive data sets and applied them to common NAWARO crop rotations in different soil climate zones in Germany**
- **Our sensitivity studies make it clear that the uncertainties of soil data are particularly relevant for the accuracy of modelled nitrous oxide emissions with biogeochemical models.**
- **The scenarios on productivity and GHG emissions calculated throughout Germany show that the GHG reduction potential of bioenergy plants are strongly influenced by weather and soil conditions.**

Background and Objectives

Greenhouse gases (GHG) are produced when using energy and operating resources, for the cultivation of renewable raw materials (NAWARO) and when converting them into usable energy sources (e.g., biogas, biofuel). Of these, direct and indirect nitrous oxide emissions from cultivated areas in particular are not easy to quantify. They are caused by microbial degradation processes, the intensity of which depends on the interplay of natural conditions such as weathering, soil properties and the cultivation methods used.

There are model approaches of varying complexity that describe this interaction and thus enable estimates of GHG emissions. Biogeochemical process-oriented models can also be used to quantify crop yields and nitrate leaching from NAWARO systems. The benefits of NAWARO systems can only be evaluated and measures to reduce GHG emissions can only be conceived if all GHG emissions are known and set in relation to the energy yield produced.

In this work, process-based models were used to quantify regionalized estimates of direct nitrous oxide emissions from typical NAWARO crop rotations in Germany. With the help of BIOGRACE II, a tool for calculating GHG balances for energy production from biomass, and various GHG indicators, it was thus possible to evaluate region-specific GHG balances.

Models are always simplified descriptions of reality. The more complex they are, the greater their data requirements and the greater their uncertainties. This also limits their suitability for evaluating and optimizing NAWARO systems. In the THG EMOBA project, we therefore investigated how data availability and model complexity influence the estimation of land-use-related nitrous oxide emissions.

Methods

We first created a data set that combines the available and suitable data for modelling field experiments from 29 arable sites with 344 trial variants in Germany. The data, with measurements of direct nitrous oxide emissions, nitrate content in the soil and crop yields, were checked for quality and plausibility. Data gaps were closed using algorithms for predicting properties from soil data (pedotransfer functions), data from the German Weather Service (DWD) and publications. Using this data set, process-oriented models (DNDC-CAN, HUME) and stochastic approaches (MODE, GNOC) were evaluated for their suitability to represent observed nitrous oxide emissions and crop yields.

We then used this data set to evaluate biogeochemical models (DNDC-CAN, HUME) and stochastic approaches (MODE, GNOC) with regard to their suitability for modelling observed nitrous oxide emissions and crop yields. To test how sensitive the models react on uncertain input data, the locally available data describing soil and weather conditions were replaced by data sets that are available nationally but have higher local uncertainties. The result of this analysis is essential for the large-scale application of these models.

To calculate regional GHG potentials in Germany, representative locations were selected from the Soil Condition Survey for Agriculture (BZE-LW, Jacobs et al. 2018). Soil climate regions, as defined by Roßberg et al. (2007), served as the basis for this. For these locations, we calculated region-specific nitrous oxide emissions from typical NAWARO crop rotations. By combining these with system-specific standard emissions from the bioenergy production methods used, we were able to determine area- and yield-specific GHG indicators.

Results

Our sensitivity studies showed that biogeochemical models are more sensitive than stochastic models to uncertainties in national data sets on soil properties and weather conditions.

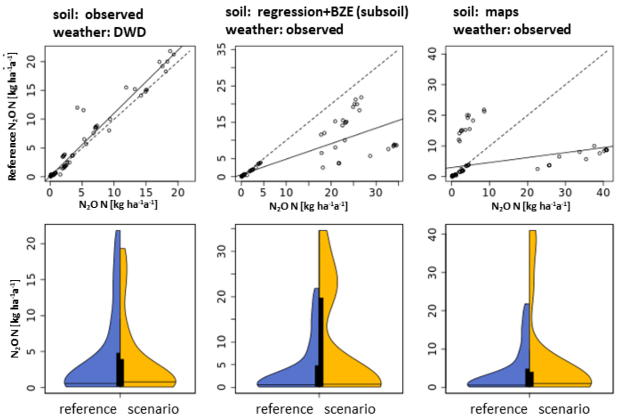

Fig.1: Effects on annual modelled nitrous oxide emissions (top) and their frequency distributions (bottom) when locally measured weather and soil data ("observed") are replaced by nationally available data sources (weather: DWD, subsoil: regression models + BZE, topsoil: maps).

In the case of modelling direct nitrous oxide emissions, uncertainties in the description of the physical and chemical topsoil properties proved to be particularly relevant (Fig. 1).
Depending on the model used and the respective crop type, however, uncertain soil data had only a moderate effect on modelled plant yields. The effect of uncertain soil properties (alone and in combination with uncertain weather conditions) proved to be relevant for modelled nitrate leaching in both HUME and DNDC-CAN.
Scenarios were calculated for the bioenergy lines maize (for electrical energy), rapeseed (for biodiesel) and wheat (for bioethanol) in order to illustrate the influence of local soil and weather conditions on the development of GHG indicators. These include: Energy yield per area, specific emissions per energy unit, GHG savings from the climate gas balance, GHG reduction compared to the fossil reference.
This showed that direct nitrous oxide emissions have a major influence on the GHG indicators "specific emissions per unit of energy" and "GHG reduction compared to the fossil reference" (Fig. 2). This makes it clear that site conditions that determine the formation of direct nitrous oxide emissions are also relevant for the climate compatibility of the respective bioenergy lines.
Scenarios for the spatial distribution of direct nitrous oxide emissions were calculated using the HUME and DNDC-CAN models. This indicates a gradient from east to west, with lower nitrous oxide emissions in the east, where there is less precipitation. It also showed that for the rapeseed and wheat-based bioenergy lines, slightly less than half of the locations are below the eligible GHG reduction (according to: Renewable Energy Directive RED II).

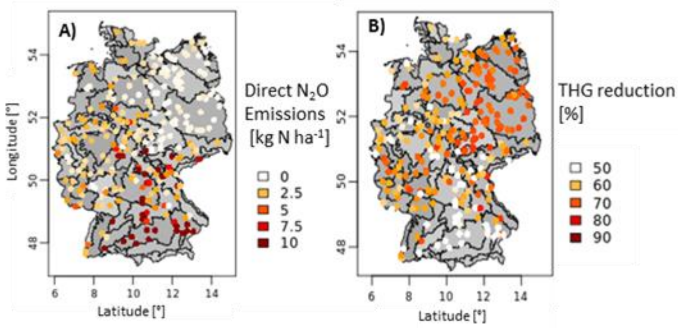

Fig.2: A) Spatial distribution of modelled annual GHG emissions as mean of the years 2000 to 2019 for the bioenergy line biodiesel from canola (fertilization according to fertilization ordinance) in Germany calculated with DNDC-CAN B) GHG reduction compared to GHG emissions of substituted fossil fuels

Conclusions

This study shows the potential of process-based modelling in the evaluation of management systems for the reduction of GHG emissions. However, it also makes it clear that there are still relatively high forecast uncertainties due to structural model uncertainties and data uncertainties in process-based modelling. With the compilation of evaluation data sets and analyses of modelling uncertainties, prerequisites were created for the further development of approaches for better model-based quantification and assessment of GHG emissions from agricultural production systems.

Further Information

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