International Max Planck Research School on

EARTH SYSTEM MODELLING

"Modelling of global crop production and resulting N_2O emissions"

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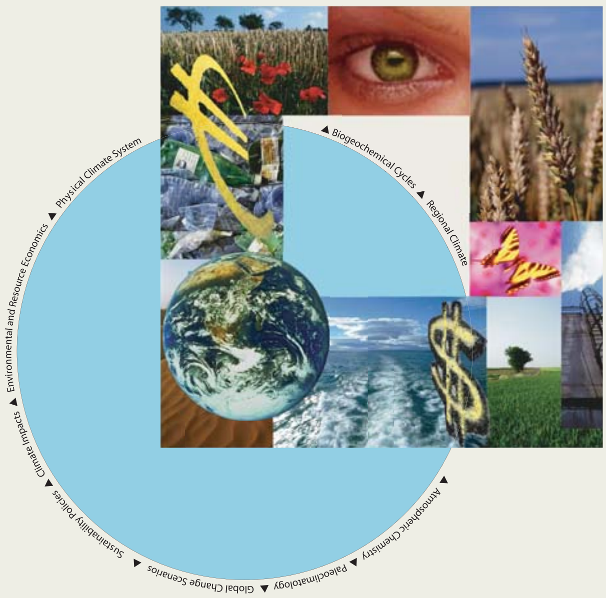
PhD Thesis prepared within the
International Max Planck Research School on
Earth System Modelling



Summary

Agricultural systems play a central role in the earth system. They contribute to the anthropogenic greenhouse effect via the emission of CO_2, CH_4 and N_2O, can cause soil degradation and eutrophication of downstream ecosystems, may change regional water cycles and will be strongly affected by climate change. All these processes are strongly interconnected and therefore need to be addressed in a consistent approach. However, knowledge and data gaps have hindered the development of such a modelling framework until recently.

In this thesis, a first version of such a consistent global modelling framework is presented, focussing primarily on the simulation of global crop yields and resulting N_2O emissions for the following reasons: First of all, the correct representation of plant growth is a precondition for the simulation of all other processes, and actual and potential crop yields are important driving forces of land-use change and will strongly be affected by climate change. The second focus is on N_2O emissions, as no process-based N_2O model has been applied at the global scale so far.

The existing agroecosystem model Daycent was used as a basis for the consistent modelling of agricultural production and its environmental effects. As a preparatory step, a computational framework for grid-based calculations was developed, and the required global input datasets for soil, climate and agricultural management were compiled. As no global inventory of planting dates existed yet, and as planting dates need to be adjusted under climate change conditions, an algorithm was developed to calculate planting dates of major crops. Results correspond to FAO crop calendars, which are available for a number of countries and crops.

Thereafter, Daycent was parameterised and calibrated to simulate yield levels for wheat, maize, rice, soybeans, tropical cereals, pulses, potato, cassava and cotton. Simulation results show that the Daycent model is capable of reproducing the major effects of climate, soil and management on crop production. Average simulated crop yields per country agree well with FAO data ($R^2 \approx 0.66$ for wheat, rice and maize; $R^2 = 0.32$ for soybean), and spatial patterns of yields mostly correspond to observed crop distributions and subnational census data.

Preceding the modelling of N_2O emissions from agricultural soils with the Daycent model, a statistical analysis of N_2O and NO emission measurements from both natural and agricultural ecosystems was carried out. Similarly to a previous analysis, fertilization rate, soil organic carbon content, soil pH, texture, crop type, and fertilizer type significantly affect N_2O emission from agricultural soils, while NO emissions are significantly determined by fertilization rate, soil nitrogen content, and climate. For emissions from soils under natural vegetation, which had not been subject to such a statistical analysis before, N_2O emissions are significantly affected by soil carbon content, soil pH, bulk density, drainage, and vegetation type, while NO emissions are significantly influenced by carbon content and vegetation type. Based on the resulting statistical models the global annual emissions from fertilized arable land sum up to 3.3 Tg N y^{-1} for N_2O, and to 1.4 N y^{-1} for NO. Statistical models are valuable to calculate best estimates and uncertainty ranges of N_2O and NO emissions based on a plenty of measurement data. However, the dynamics of soil organic nitrogen pools, as especially affected by crop production, climate change and land-use change can only be included by applying process-based agroecosystem models

For the modelling of global N_2O emissions with the Daycent model, its trace gas module was improved by implementing a more detailed representation of nitrification/denitrification processes, and by including freeze-thaw emissions. This revised model version was tested against N_2O emission measurements of agricultural soils under different climate regimes and crop types. Simulation results show that annual emissions are represented well, and that the modelling efficiency on a monthly basis ranges between 0.1 and 0.66 for most sites.

Based on this revised Daycent version, N_2O emission rates are calculated for all crop types for which the Daycent model had been parameterised before. Emission rates and differences between crop types mostly agree with literature. Fertilizer induced emissions, which are currently estimated by the IPCC as 1.25 +/- 1% of the N applied, range between 0.77% (rice) and 2.76% (maize). Simulated N_2O emissions from agricultural soils in the 1990ies add up to 2.1 Tg N_2O-N y^{-1}, which is similar to the estimates from other studies.