Modelling climate-smart options for the management of nitrogen on agricultural land

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Overview

The grand societal challenge of managing natural resources effectively under environmental change is central to the future management of agricultural land. Sustainable agriculture aims, amongst other things, to grow food whilst also reducing negative environmental impacts. These include greenhouse gas emissions, where agriculture currently accounts for about one third of the global total. There are implicit trade-offs in achieving sustainable agriculture. For example, if soils are managed solely to maximise productivity, there can be significant losses of reactive nitrogen (N) to the environment through nitrate leaching, emissions of nitrous oxide to the atmosphere and ammonia volatilization. Increasing the efficiency of crop nutrient uptake is essential to reduce losses and increase yields.

More broadly, the interactions between land use, greenhouse gas emissions, and soil health are complex. For example, the retention of crop residues in fields as mulch is strongly promoted as a sustainable intensification approach for its benefits in increasing soil organic matter, improving water infiltration, reducing erosion and cycling N and other nutrients. However, crop residues can also be used as feed and fodder for livestock. Hence there are a series of trade-offs involved in managing natural resources sustainably.

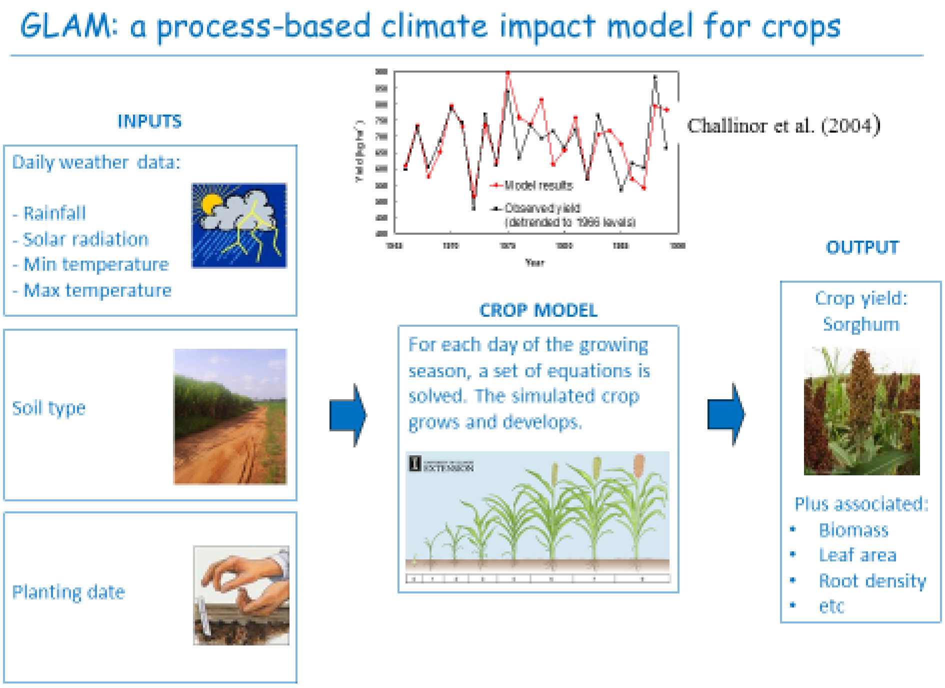
Climate-smart agriculture (CSA) refers to a set of practices that to some degree or other achieve low emissions and high productivity, through managing the inherent trade-offs. It also seeks to deliver adaptation by increasing resilience to the challenges that farmers face under climate change and thus increasing the capacity of the system to prosper in the face of climate shocks or long-term stresses.

Much of the focus of CSA to date has been on low-carbon technologies. Nitrogen is a feature of existing CSA analyses in that the application of commercially produced N fertiliser directly implies increased emissions from the industrial processes involved. This project takes a nitrogen-centric view of CSA by bringing together a set of emerging tools to look at nitrogen cycles and associated trade-offs, such as crop residue retention vs fodder question.

The nitrogen cycle, along with the partitioning of other compounds, is also important in determining the nutritional content of food. Whilst the modelling of climate and its impacts on crops is well developed, the processes that determine nutritional content have only just begun to be incorporated into models. For example, whilst N limitation is known to be an important issue for grain yields under climate change (nitrogen is needed in order for crops to benefit from the CO_2 fertilisation effect), only recently has it been shown to have an effect on protein yields (Asseng et al., in press).

Methods and data

Climate and crop modelling are used around the globe to assess climate impacts and develop adaptation options. Field-scale crop models for decision support have a long history (Hoogenboom et al., 1994) that in turn enabled frameworks to link crop and climate models (Challinor et al., 2003). The need to quantify uncertainty (Challinor et al., 2013) has led to work supporting the use of crop models with climate ensembles (Ramirez-Villegas et al., 2013). Crop model improvement is essential if the roles of the nitrogen cycle in delivering both CSA and nutrition security are to be understood. Correct simulation of N remobilization rates and parameterisation of leaf senescence are key.



Soil science. Three of the top priorities for soil science research in the 21st century, according to Adewopo et al. (2014), are: (1) fertilizer use impact on ecosystem functioning, on public health and human well-being, and on nutrient cycling; (2) plant–soil–microorganism interactions; and (3) soil transport processes. Nitrogen use in agriculture is related to all three priorities. Critically, soil N not taken up by plants remains available for mineralization, leaching, and volatilization as ammonia or nitrous oxide, which threaten the environment (Rosolem et al., 2017). To increase nitrogen use efficiency (NUE) of crops, it is important to ensure appropriate plant uptake for crop production and to decrease losses from the agricultural system including immobilization in the soil. For example, it has been estimated that there is only a 33% recovery of applied nitrogen fertilizer in harvested grains (Raun and Johnson, 1999). Increases in NUE and reductions of surplus applied N in agriculture should eventually lead to lower N pollution.

Extensive data exist for the project. There will be field trial data sets available to this studentship, including: 1) analytical data from the Africap project on N content of soil and a nutrient content of maize kernels grown under controlled CA regimes (in collaboration with Plant Sciences and Prof Dougill); 2) nutrient analytical data from FACE experiments in wheat kernels grown under various stresses (in collaboration with DTU, Denmark). 3) Data from the Agricultural Model Intercomparison and improvement Project, especially the Low Input study, which uses four sites across Africa with contrasting ago-ecologies and soil conditions[1]. Data available include crop phenology, yield, LAI, in-season soil moisture, soil mineral N and plant N. These unique data sets will allow the models to be extended to test impact on N regimes under various environmental conditions on N (and therefore protein) content of food crops.

[1] http://www.agmip.org/wp-content/uploads/2018/08/AgMIP7-Report-Back-Template_low-input_GF.pdf

Novel Methodology

Examining the role of the nitrogen cycle in climate-smart agriculture requires improved treatment of nitrogen in crops models. The student will use the latest version of the General Large Area Model for annual crops (GLAM; Challinor et al., 2004), which operates by solving a system of simultaneous equations using an iterative numerical method. This novel approach enables the tracking of nitrogen content in the crop. The student will therefore parameterise the temporal dynamics of nitrogen content in the various parts of the crop by developing and implementing a novel crop-nutrient-uptake subroutine and nutrient translocation methodology.

The student will use the newly-developed nitrogen module in GLAM in order to simulate key processes in the nitrogen cycle in the soil module (e.g. hydrolysis, mineralisation, fixation, volatilisation, nitrification and denitrification in root zone; Li et al., 2015) The developed model will numerically solve one-dimensional advection-dispersion-reaction (ADR) equation in variably saturated soil column.

Training and research environment

The student will be based in the School of Earth and Environment (SEE) at Leeds, with more than 220 fellow PhD students. He/she will benefit from the School's first class research facilities and from outstanding job prospects in government, academia, research and industry. The student will be a member of the Climate Impacts Group, an active team of researchers working on developing and using climate and crop models to quantify the impacts of climate variability and change on crop yield, including associated uncertainties and adaptation options. The group meets twice a week: once for scientific exchange, and once for an informal lunch.

The student will be co-supervised by Dr. Caroline Orfila from the School of Food and Nutrition, who brings expertise on the nitrogen and other nutritional elements and compounds to the supervisory team.

Training will be provided to cover familiarisation with the complex modelling tools and data involved. PhD students at Leeds also undertake a 2-day induction course, which includes an overview of regulations relating to research degree students; health and safety briefing; skills training, and departmental finance guidelines. Students complete with their supervisor a training needs assessment within 1 month of starting. They manage their research training using an on-line Personal Development Record where all training courses and monthly meetings are uploaded. This is used to plan and reflect on what skills are being developed.

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