Managing phenology for agronomic adaptation of global cropping systems to climate change

Abstract:

Climate change is posing a challenge to current cropping systems, if production levels are to be maintained or even enhanced. Despite some positive effects that might derive from higher concentrations of CO_2 in the atmosphere, future trends in temperature and precipitation are expected to negatively impact crop productivity (yields and production), especially in regions that are, already today, characterized by high temperatures and water shortages. On the other hand, growing population and changing diets are expected to force up the global demand for agricultural products. Therefore, exploring possible solutions for the adaptation of cropping systems to a changing climate is of high interest, making best use of the available knowledge, resources and technologies.

Crop models are the most frequently used method for estimating future climate change effects on global crop productivity. For long, crop modelling studies have been conducted without accounting for changes in the agronomic management that farmers might implement in response to climate change. This omission has been caused by data scarcity on management practices, especially at the global scale. This has come along with a low level of understanding on how agronomic decisions are taken and how they evolve over time. The increasing availability of global management datasets allows for an improvement of historical and present crop productivity estimates. Yet, to provide insights in future management changes, more research is needed.

The aim of this thesis is to advance knowledge on the adaptation of world-wide relevant grain crops to climate change. The central research question is whether global cropping systems can be adapted to climate change by managing crop phenology through adjusting growing periods and cultivars. While advancements have been made in understanding sowing dates decision making, large knowledge gaps exist on crop cultivar choice which will be addressed by this thesis.

The first step in the analysis is to systematically assess phenology and yield responses to temperature increase and cultivar selection, making use of an ensemble of Global Gridded Crop Models. Results show that phenology is a key mechanism of temperature impact on crop yields and that the use of cultivars that maintain original growing periods is an effective strategy to compensate temperature-induced crop production losses. Yet, full compensation is possible only up to 2 K of warming (globally uniform temperature increase in space and time) and declines thereafter. Moreover, this study emphasizes the complexity of adaptation via phenological management, motivating the next step of the analysis.

In the second study, a novel approach is proposed to formalize farmers' decision-making for choosing cropping periods adapted to local climate. The outcome of the analysis is a rule-based algorithm that selects crop phenological cycles aiming at maximizing the time for yield formation and minimizing temperature and water stresses during the crop growth cycles. This study complements previously published approaches to simulate climate-driven sowing dates.

Finally, rule-based computed sowing dates and growing periods are used to parametrize global patterns of cultivars adapted to present and future climate scenarios and to quantify their effects on global crop production. Results indicate that rule-based crop phenology adaptation can aid alleviating negative impacts of temperature increase and help exploiting positive effects due to the CO_2 fertilization effect.

Overall, this thesis demonstrates that the impacts of climate change on crop productivity can vary substantially, depending on which assumptions are made on agronomic management. In all cases explored here, scenarios that neglect any changes in management return the most pessimistic projection on future crop production. Relatively simple approaches to compute adapted sowing dates and cultivars provide a base for considering autonomous adaptation schemes as an integral component of global scale modelling frameworks.