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Improving the use of crop models for risk assessment and climate change adaptation

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ABSTRACT

Crop models are used for an increasingly broad range of applications, with a commensurate proliferation of methods. Careful framing of research questions and development of targeted and appropriate methods are therefore increasingly important. In conjunction with the other authors in this special issue, we have developed a set of criteria for use of crop models in assessments of impacts, adaptation and risk. Our analysis drew on the other papers in this special issue, and on our experience in the UK Climate Change Risk Assessment 2017 and the MACSUR, AgMIP and ISIMIP projects.

The criteria were used to assess how improvements could be made to the framing of climate change risks, and to outline the good practice and new developments that are needed to improve risk assessment. Key areas of good practice include: i. the development, running and documentation of crop models, with attention given to issues of spatial scale and complexity; ii. the methods used to form crop-climate ensembles, which can be based on model skill and/or spread; iii. the methods used to assess adaptation, which need broadening to account for technological development and to reflect the full range options available.

The analysis highlights the limitations of focussing only on projections of future impacts and adaptation options using pre-determined time slices. Whilst this long-standing approach may remain an essential component of risk assessments, we identify three further key components:

1. Working with stakeholders to identify the timing of risks. What are the key vulnerabilities of food systems and what does crop-climate modelling tell us about when those systems are at risk?
2. Use of multiple methods that critically assess the use of climate model output and avoid any presumption that analyses should begin and end with gridded output.
3. Increasing transparency and inter-comparability in risk assessments. Whilst studies frequently produce ranges that quantify uncertainty, the assumptions underlying these ranges are not always clear. We suggest that the contingency of results upon assumptions is made explicit via a common uncertainty reporting format; and/or that studies are assessed against a set of criteria, such as those presented in this paper.

1. The role of crop models in assessing risk and adaptation

Crop models have a long history, during which their focus and application have altered in response to societal needs (Jones et al., 2016). They have contributed to decision support (e.g. Kadiyala et al., 2015) and risk assessment (e.g. Rader et al., 2009), and have resulted in conceptual and practical advances in publicly-funded agricultural development work (Reynolds et al., this issue). The last decade has seen an increase in the use of crop-climate ensembles targeted at informing adaptation (e.g. Challinor et al., 2013). Much of the progress made has

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been enabled by model intercomparison projects (MIPs). The Agricultural Model Intercomparison and Improvement Project AgMIP (Rosenzweig et al., 2013b), the Inter-Sectoral Impact Model Intercomparison Project ISIMIP (Warszawski et al., 2014), and Modelling European Agriculture with climate change for Food Security MACSUR (Bindi et al., 2015) have brought together large model ensembles that are run for different sites and crops or in gridded form for larger areas or globally.

Food systems risks can be defined narrowly as the potential for reduced food production (e.g. Li et al., 2009), or broadly as the risk to food security. Even more broadly, food systems have many interactions with other systems, e.g. the energy system (Homer-Dixon et al., 2015). Crop models will have a greater or lesser role in the analysis, depending on the nature of the risks being assessed. The UK Climate Change Risk Assessment (CCRA2017)[1] aimed to identify all the climate risks requiring action by the UK government – i.e. all those that are not addressed by current policy. Topics covered in CCRA2017 include domestic food production and international dimensions of risk, including food security, conflict, migration and humanitarian aid, and their interrelationships (see Challinor et al., 2016b).

Integrated assessment of risks from climate change is a relatively recent focus for crop modelling. Ewert et al. (2015) have set out a valuable review and outlook for risk assessment using crop models as part of integrated assessment models. Here, we examine the use of crop models for risk assessment outside of this emerging field. We draw on author experience in both MIPs and CCRA2017. Our analysis is also based on a list of criteria for application of crop modelling to impacts, adaptation and risk assessment; and on a list of identified research priorities for the crop-climate modelling research community. These lists, which can be found in Section 1 of the supplementary information, were developed first amongst the authors and then distributed more widely amongst all authors of this special issue, to ensure feedback and consensus. The manuscript reviews were also used to refine the lists.

Our analysis reviews and assesses the frameworks needed for risk assessment (Section 2); the development and running of crop models (Section 3); the methods used to form crop-climate ensembles (Section 4); and the methods used to assess adaptation (Section 5). Good practice in all of these areas underpins accurate risk assessment. We conclude with a forward-looking assessment of how crop models might be better used to improve risk assessments (Section 6). The key issues identified in our analysis are presented in Fig. 1.

2. Towards improved framing of risks posed by climate change to food production systems

2.1. Risk, uncertainty and likelihood

Risk and uncertainty are concepts that apply where the range of future possibilities is largely known (Stirling, 2010). The difference between them lies in whether or not probabilities can be calculated (Wynne, 1992). This distinction is often a matter of (expert) opinion rather than provable fact, so that the same crop-climate ensemble can be presented as an assessment of risk or as an assessment of impacts expressed using uncertainty ranges. True assessment of risk implies a knowledge of the consequences of an event, since risk is the product of two factors: the probability that an adverse event will occur and the consequences of that adverse event (Jones, 2001). For simplicity, however, and following the conventional use of the term “risk” in much of the crop modelling literature, we do not distinguish here between likelihood and risk. Clearly any contribution to the assessing likelihood can be a component of a risk assessment.

2.2. Frameworks for interconnected risks

Interactions between sectors (e.g. agriculture, forestry, water) are important in determining climate change impacts (Harrison et al., 2016, Elliott et al., 2014, Piontek et al., 2014). In CCRA2017, a very broad systems boundary was needed in order to draw the most robust conclusions possible. Where quantitative information on interactions was not available, those relationships were assessed using existing literature. Studies that focus on interactions often fill key knowledge gaps. Guzman et al. (this issue) provide an exemplar study of interactions between crop cultivation, irrigation and groundwater. Elliott et al. (this issue) provide an exemplar study of economic impacts by assessing the insured and uninsured crop losses resulting from drought.

The interactions that lead to climate change risks go beyond those amongst ecosystem-based sectors and into governance, society, health and economics, to name but a few areas. Fig. 2 summarises those findings of CCRA2017 that relate to food security (Challinor et al., 2016b). Key issues that emerged in that assessment are the fundamental interconnectedness of both climatic and non-climatic risks and the transmission of risks across international boundaries (e.g. transnational transmission of risks to crops from ozone Hollaway et al., 2011). Thus, the relevance of crop modelling goes well beyond an understanding of food production, or even food security, and there is a concomitant breadth required in the systems boundaries used in crop modelling studies (Campbell et al., 2016, Waha et al., 2012), especially where broad system boundaries are used.

Integrated assessment models (IAMs) may be expected to deliver frameworks for interconnected risks; however the use of crop models within IAMs is at a relatively early stage (Ewert et al., 2015). Further, IAMs may not be the best tool to assess the range of trade-offs and synergies that are important to food systems. The complexity of the inter-related set of climate change and food security risks and responses has led to them being labelled a “wicked problem” requiring a range of approaches (Vermeulen et al., 2013). Food security targets are not solely a matter of increasing yield, but also of improving food access, quality and diversity. There may be direct yield trade-offs involved in actions and activities that contribute towards food security (Campbell et al., 2016). The integration of local knowledge and the input of social scientists within interdisciplinary modelling research can contribute to the identification and outlining of realistic scenarios of socio-technical change, crop-climate indices, or of model output priorities (i.e. not solely yield Herrero et al., 2015, Campbell et al., 2016). The insights gained may inform the design of models and modelling studies that go beyond conventional projections of yield and yield response and are designed to analyse trade-offs (Wessolek and Asseng, 2006), determine least regrets options, or inform multi-criteria analyses (Hallegatte, 2009, Challinor et al., 2010).

2.3. Joint adaptation and mitigation frameworks

Much of the current focus on assessing the risks of climate change is focused on the stringent 1.5–2 °C limit on global warming agreed at the international climate negotiations in Paris in 2015 (COP21). In order to be consistent with a 2 °C target, emissions across all sectors need to decrease by over 80% by 2050 (Edenhofer et al., 2012), with even greater reductions required for a 1.5 °C target. The agriculture, forestry and other land use sector is responsible for 24% of all human greenhouse gas (GHG) emissions (Smith et al., 2014), so is a critical sector for delivering the Paris Agreement. More than even before, it is clear that agricultural systems require changes that address both adaptation and mitigation.

Both sustainable intensification and climate-smart agriculture (Lipper et al., 2014) seek to address the challenge of joint adaptation and mitigation challenge. Climate-smart agriculture targets the simultaneous achievement of increasing agricultural production, adapting to climatic change, and mitigating this change through

[1] https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/.