Institution: University of Reading

Unit of Assessment: 6 Agriculture, Veterinary and Food Science

Title of case study: Crops and climate change research informs international policy

1. Summary of the impact

A novel large-area process-based crop simulation model developed at the University of Reading and published in 2004 has been used to explore how climate change may affect crop production and global food security. The results of Reading's modelling work have been used as evidence to support the case for action on climate change for international agreements and used by the UK Government to inform various areas of policy and, in particular, to help frame its position on climate change at international negotiations. The database and knowledge from this model also informed the development of Reading's innovative web-based tool that locates sites where the climate today is similar to the projected climate in another location – providing insight into potential adaptation practices for crop production in the future by linking to present-day examples. This tool has been used to inform and train farmers and policy-makers in developing countries and has supported policy implementation of the International Treaty on Plant Genetic Resources for Food and Agriculture.

2. Underpinning research

Research conducted at the University of Reading since the mid-1990s has investigated the responses of crops to various climate change scenarios. Led by Tim Wheeler, Professor of Crop Science (1994-present), together with Reading colleagues Richard Ellis (Professor of Crop Production, 1977-present), Paul Hadley (Professor of Horticulture, 1977-present) and later Peter Craufurd (Senior Research Fellow,1997-2009), this work has explored how variability in factors such as temperature and carbon dioxide (CO_2) level affect crop development and yield [1], [2]. Wheeler and his colleagues conducted extensive plant experiments in custom built controlled environment facilities to measure the effects of changes in key climate change parameters (with particular attention given to changes in temperature) on plant development and growth for a number of key crops including rice, wheat, groundnuts and soybean.

Development of a novel large-area process-based crop simulation model

The Reading team used these research findings in conjunction with other available data to develop a new process-based crop simulation model that enabled the simulation of climate impacts on crop yield at a global scale. Reading's Dr Andy Challinor (Senior Research Fellow, 2005-2007), joint appointment between the School of Agriculture, Policy and Development & the Department of Meteorology) and Wheeler, together with colleagues in the University's Department of Meteorology, developed a method for combining weather and crop yield forecasting systems. To do this, the team had to overcome a disparity in spatial scales as crop models generally perform well at the field scale, while climate models operate at regional and global scales. Using observational weather and yield data for groundnut in India recorded from 1966 to1990, they established a working spatial scale of an order comparable with the resolution of regional and general circulation models of climate. In 2004, they published the design and optimisation of this novel crop model, named GLAM (General Large Area Model), which was developed so that it could easily be extended to any annual crop for the investigation of the impacts of climate variability on crop yield over large areas [3].

Wheeler and his colleagues subsequently developed new parameter sets for GLAM based upon their experimental studies on crop responses to variability in CO_2, temperature and water availability. Their work has helped improve understanding of the circumstances under which different abiotic stresses dominate and has helped to quantify the uncertainty inherent in the paramaterisation of crop growth and development [4]. The Reading team, including Dr Hooker (Post-doctoral Research Fellow, 2008-2012), Dr Osborne (Research Scientist, 2005-2008) and Dr Rose (Teaching Fellow, 2008-present) also demonstrated the uncertainty introduced to a crop impact assessment as a result of using different climate General Circulation Models (GCMs) [5].

Application of GLAM

The GLAM crop model went on to be used as part of the AVOID research programme, which is

funded by the Department of Energy and Climate Change (DECC) and Department for Environment, Food and Rural Affairs (Defra), and aims to provide key advice to the UK Government on avoiding dangerous climate change brought on by greenhouse gas emissions. The Reading team contributed to the AVOID programme by using GLAM to examine the impact that potential climate change mitigation policies may have on crops by comparing global yield of key crops in mitigated and unmitigated scenarios [6]. The GLAM model has been used by others elsewhere to run simulations for crops growing under different climate change scenarios across the world, in order to understand how they would respond to projected environmental change and to highlight specific vulnerabilities to climate change and the potential benefits of mitigation or adaptation strategies.

Development of a new Climate Analogue Tool

As an alternative but complementary approach to informing agricultural adaptation to climate change, the knowledge and datasets from the GLAM global modelling work were used by the Reading team to develop a tool to identify sites or time periods that experience statistically similar climates – known as analogue climates. This work was undertaken as part of the Climate Change, Agriculture & Food Security (CCAFS) programme of the global Consultative Group on International Agricultural Research (CGIAR), in collaboration with the International Center for Tropical Agriculture, and the Climate Impacts Group at the University of Leeds. This novel approach provides useful insights and practical knowledge to support the evaluation and formulation of agricultural adaptation options and strategies. Reading researchers developed both the original idea for the Climate Analogue Tool and the coding foundation for core functions within the software package. Collaborators then further developed the software and validated it by applying it to various case studies.

3. References to the research

The outputs listed below have all been published in peer-reviewed journals and have also been internally peer-reviewed and assessed as of at least 2* quality.

[1] Wheeler T.R., Batts G.R., Ellis R.H., Hadley P., and Morrison J.I.L. (1996). Growth and yield of Winter Wheat (*Triticum aestivum*) crops in response to CO_2 and temperature. *Journal of Agricultural Science*, 127, 37-48. DOI: 10.1017/S0021859600077352

[2] Vara Prasad P.V., Craufurd P.Q., Summerfield R.J. and Wheeler T.R. (2000). Effects of short episodes of heat stress on flower production and fruit-set of groundnut (*Arachis hypogaea* L.). *Journal of Experimental Botany*, 51, 777-784. DOI: 10.1093/jexbot/51.345.777

[3] Challinor A.J., Wheeler T.R., Craufurd P.Q., Slingo J.M. and Grimes D.I.F. (2004). Design and optimisation of a large-area process-based model for annual crops. *Agricultural and Forest Meteorology*, 124, 99-120. DOI: 10.1016/j.agrformet.2004.01.002

[4] Challinor A.J. and Wheeler T.R. (2008). Use of a crop model ensemble to quantify CO2 stimulation of water-stressed and well-watered crops. *Agricultural and Forest Meteorology*, 148, 1062-1077. DOI: 10.1016/j.agrformet.2008.02.006

[5] Osborne T., Rose, G. and Wheeler T. (2013). Variation in the global-scale impacts of climate change on crop productivity due to climate model uncertainty and adaptation. *Agricultural and Forest Meteorology,* 170, 183-194. DOI:10.1016/j.agrformet.2012.07.006

[6] Arnell N.W., Lowe J.A., Brown S., Gosling S.N., Gottschalk P., Hinkel J., Lloyd-Hughes B., Nicholls R.J., Osborn T.J., Osborne T.M., Rose G.A., Smith P. and Warren R.F. (2013). *A global assessment of the effects of climate policy on the impacts of climate change. Nature Climate Change*, 3, 512 – 519. DOI: 10.1038/nclimate1793

Grants

[7] Wheeler (2004-2007) *Assessing the impacts of climate change on crops*, Defra/Met Office, £111,852.

[8] Wheeler (2004-2009) *Ensembles-based predictions of climate changes and their impacts*, European Commission, £101,562.

[9] Wheeler, Challinor, Slingo & Osborne (2007-2010) *Global impacts of climate change: a multi-sectoral analysis,* NERC, £124,099.

[10] Wheeler & Osborne (2008-2009) *Development of JULES-crop*, NERC, £160,000.

Wheeler (2008-2011) *Global impacts of climate change on crop production*, Defra/Met Office, £186,480.

4. Details of the impact

The Food and Agriculture Organization of the United Nations estimates that the world needs to produce 60% more food by the year 2030. Increased production is needed to support a growing global human population and to accommodate changes in diet. However, our ability to maintain, let alone increase, food production will be hindered by climate change; under a 'business as usual' scenario, levels of global productivity will steadily decline. Food security is further threatened by the negative impacts of extreme weather, which is expected to become more frequent. The University of Reading's work on crops and climate change has informed international policy related to measures to safeguard global food security by: i) providing evidence to support the UK Government's position in international climate change discussions, ii) providing key evidence for the 2010 United Nations 16th Conference of the Parties (COP-16), iii) developing new tools to support the training of farmers, researchers and policy makers in the developing world, and iv) supporting the International Treaty on Plant Genetic Resources for Food & Agriculture.

i) Advising UK Government

The GLAM crop simulation model has been used by Reading researchers to explore the impact of a range of potential climate change mitigation policies on crop production to inform policy decisions through the AVOID programme.

The results of Reading's work on crop productivity, together with projections of other potential impacts undertaken by collaborators within the AVOID programme, have been made available to DECC. These outputs have included reports for DECC as well as presentations, posters and information leaflets at key global conferences and meetings for policy makers such as the 2009 United Nations Climate Change Conference (COP-15) in Copenhagen, a pre-COP-16 briefing in Cancun in 2010, and the Planet Under Pressure conference in London 2012 (over 3000 delegates plus 3,500 virtual delegates on the web). According to an independent review of the AVOID programme "the programme's outputs have been used by policy makers in DECC and other areas of government" [a, pg 4] and have "helped frame the UK position at negotiations and the Committee on Climate Change's work on long term targets to 2050" [a, pg 4]. The AVOID outputs were used as part of the evidence for the UK Climate Change Risk Assessment 2012, which is "a major piece of evidence in Defra" [a, pg 6].

Reading research has also fed into the Commission on Sustainable Agriculture and Climate Change [b, cites 4], which was chaired by the UK's Chief Scientific Adviser at the time, Professor Sir John Beddington. Sir John has used outputs from both AVOID and the research of the Commission as a source for speeches to a variety of audiences [a, pg 5].

ii) Evidence for international agreements adopted at COP-16

The GLAM crop model simulations were incorporated into evidence that was distributed to approximately 15,000 delegates at the 16th Conference of the Parties (COP-16) to the United Nations Framework Convention on Climate Change at Cancun, Mexico in 2010 [c]. The evidence presented in information packs demonstrated the potential impacts of mitigated and unmitigated climate change, including the crop impact data from Reading. This included a comparison of impacts at 2°C and 4°C global warming.

The outcome of COP-16 was an agreement adopted by the states' parties. The agreement recognized that climate change represents an urgent and potentially irreversible threat to human societies and the planet, which needs to be urgently addressed. The agreement further recognized that deep cuts in global greenhouse emissions are required to hold the increase in global average temperature below 2°C above pre-industrial levels, and that parties should take urgent action to meet this long-term goal, consistent with the science. The outcome of COP-16 and the agreement to hold global average temperature at the 2°C level was built upon a wide body of scientific evidence, which included the Reading evidence on impacts of climate change scenarios on crop productivity. Whilst it is not possible to attribute the outcome to any one source of information, research from Reading made a material contribution to the larger body of evidence that informed

the decision making.

iii) Climate Analogue Tool used for training policy makers, farmers and researchers in the developing world

The Climate Analogue Tool has been, and continues to be, implemented through CCAFS. CCAFS has used the tool to support training of regional partners in the developing world, including National Agricultural Research Systems, Non-Governmental Organizations, and policy makers. The Tool is informing the development of adaptation strategies to projected climates, by ground-proofing abstract climate projections using comparisons based on present-day conditions. This allows potential options for adaptation to be identified based on existing agricultural practices in the locations where current climates are comparable with the projected future climate of the region of interest. Training and dissemination events for the Tool have been held in Nepal, Senegal, Kenya (August 2012) and Ethiopia (October 2012). This has also led to farmer-to-farmer exchange visits among climatic analogue locations, enabling individual farmers to learn from their peers about potential strategies to cope with their future climatic constraints [d].

The Tool has also been used to support farmer-to-farmer exchanges among climatic analogue locations, through the CCAFS Farms for the Future initiative. Farmers have already benefitted from the opportunity to learn from their peers about potential strategies and practices to cope with their future climatic constraints [d]. To date, Farms for the Future has facilitated exchanges for partners from Nepal, Ethiopia, Tanzania and Costa Rica.

iv) Supporting the International Treaty on Plant Genetic Resources for Food & Agriculture

The Climate Analogue Tool is supporting policy implementation of the International Treaty on Plant Genetic Resources for Food and Agriculture. No country is self-sufficient in plant genetic resources, and all depend on genetic diversity in crops from other countries and regions. International cooperation and the open exchange of genetic resources are therefore essential for food security. The fair sharing of benefits arising from the use of these resources is being proactively implemented at the international level through the Treaty and its Standard Material Transfer Agreement. The Tool is being used by Biodiversity International to demonstrate the benefits of the Treaty and associated policies, and to locate areas that need urgent conservation.

The scientist leading the Treaty implementation project for Biodiversity International, is quoted on the CCAFS website as saying "*Our work helping countries implement the Treaty dovetails beautifully with the Climate Analogue Tool, and use of the tool will be mainstreamed into the research supported by the project*" [e].

5. Sources to corroborate the impact

[a] Risk Solutions (May 2012) *Evaluation of the AVOID Programme*, A report for DECC <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48429/5597-evaluation-avoid-programme.pdf>. An independent assessment of the AVOID programme, providing evidence of how the outputs, to which Reading contributed, have been used by government.

[b] Commission on Sustainable Agriculture and Climate Change (2012) *Evidence from Major Assessment Reports on Sustainable Agriculture and Climate Change* <http://ccafs.cgiar.org/sites/default/files/assets/docs/commission_on_sustainable_agriculture_and_climate_change_matrix_of_evidence.pdf> [cites 4].

[c] AVOID (2010) *Can we avoid dangerous impacts?*, Produced by the Met Office, Crown Copyright < http://www.metoffice.gov.uk/learning/library/publications/climate-change>The results on soybean were produced by research conducted at Reading.

[d] 'East Africa moves towards implementation plans with the Climate Analogues tool', *Climate Analogues* [website] <http://www.ccafs-analogues.org/climate-analogues-arrives-in-costa-rica-this-time-for-pgr-conservation/>

[e] Cherfas, J. (17th Feb 2012) 'Climate change models may help spur lawmakers to implement seed treaty', *CCAFS & CGIAR* [website] <http://ccafs.cgiar.org/blog/climate-change-models-may-help-spur-lawmakers-implement-seed-treaty#.Unt8D_mceSo>