Institution: University of Reading

Unit of Assessment: 6 Agriculture, Food and Veterinary Science

Title of case study: Climate-resilient crops for global food security

1. Summary of the impact

Heat tolerant rice varieties, which are better adapted to predicted climate change scenarios, are critical for the future livelihood of millions of rice growers and for the 50% of the global population that depends on rice as a staple in their daily diet. Research conducted at the University of Reading has informed the development of heat-tolerant rice in two ways. Firstly, novel protocols developed at Reading for heat-tolerance screening have been adopted by rice crop breeding nurseries across Asia. Secondly, Reading researchers identified a heat tolerant rice variety that is now the basis of advanced breeding programmes. In addition, the research conducted at Reading has led to widespread recognition among international policy-makers and influencers, such as the World Bank, of the importance of high temperature extremes on crops as part of the consideration of impacts of human-induced climate change.

2. Underpinning research

Very little was known in the early 1990s about how human-induced climate change could affect crops and their productivity. Since around this time, Tim Wheeler, Professor of Crop Science, School of Agriculture, Policy and Development, University of Reading (1994 – present), has been investigating how climate change could impact on the sustainability of agriculture and food security, 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) Krishna Jagadish (PhD scholar, 1999-2002) and Madan Pal Singh (Royal Society India Fellow, 2006-2007).

Identified effect of temperature variability on crop yield

In 1996, Wheeler and colleagues discovered for the first time that in addition to mean temperature warming, temperature <u>variability</u> must also be considered when trying to quantify the impacts of future climates on crop yields [1]. Using extensive plant experiments in controlled custom-built environment facilities, Wheeler found that episodes of hot temperatures (>32^{o}C) that coincided with the flowering of annual crops drastically reduced the grain yield of wheat, and that these effects far exceeded those of a small mean temperature warming [2]. Indeed, Wheeler and colleagues showed that a period of high temperature for as little as 30-60 minutes in duration could reduce yields by anything from 50% up to 100% if it coincided with a key point in the growth of the crop, such as flowering. This effect of brief periods of high temperature on crop yields was previously unknown in the crop science community.

Further experimental research conducted at Reading quantified the threshold temperature tolerated by wheat, rice, soybean and peanut (groundnut) crops. Wheeler and his colleagues looked at responses of groundnuts – a crop often exposed to temperatures in excess of 40^{o}C - to short periods of exposure to high temperatures [3] [7]. They found that plants exposed to short, high-temperature episodes during the day produced fewer pods. These findings, along with an extensive review of existing evidence, led them to conclude that changes in the frequency of hot temperatures, which are associated with warmer mean climates, were critical to the annual yield of seed crops [4]. Understanding how crop yields are affected by temperature fluctuations, particularly very short high temperature events, independent of any substantial changes in mean seasonal temperature, was an important discovery in the context of predicting the likely impacts of climate change [8] [9]. This improved understanding is helping identify, breed and grow heat tolerant crop varieties to mitigate reduced yields in the face of climate change.

Developed protocols to screen for heat tolerance traits in crops

Beginning in 2003, the Reading team started to identify plant traits associated with heat-tolerance and they developed new and robust internationally-applicable protocols for screening wheat, rice, soybean and peanut crop varieties for heat tolerance [5]. They conducted experiments at optimum and high air temperatures using parents of some prominent mapping populations of rice (*Oryza sativa* L.) to determine a potential heat avoidance mechanism as well as to identify genotypes with a true heat tolerance during the flowering period [5]. Their research showed that the effects of temperature on the timing of flowering (heat avoidance) could be separated out from effects on the pollination process itself (heat tolerance), which allowed them to develop a screening method that identified true heat tolerance in crop varieties [5]. The N22 rice variety was the most heat tolerant rice genotype [5] [10]. The team then screened a population of 181 recombinant inbred lines of a tolerant rice cultivar x susceptible cultivar cross for heat tolerance [6]. They identified quantitative trait loci associated with heat tolerance during flowering, which were in similar positions on the chromosomes as other loci associated with stress tolerance such as drought, cold and salinity; this suggested that there were common underlying stress-responsive regions of the rice genome [6].

3. References to the research

Key outputs:

All of the research that underpins the impact is published in leading agricultural or climate science peer-reviewed journals and has been assessed internally as of at least 3* quality. The key publications are:

[1] Wheeler T.R., Batts G.R., Ellis R.H., Hadley P. and Morison 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] Wheeler T.R., Hong T.D., Ellis R.H., Batts G.R., Morison J.I.L. and Hadley P. (1996). The duration and rate of grain growth, and harvest index, of wheat (*Triticum aestivum* L.) in response to temperature and CO_2. *Journal of Experimental Botany*, 47, 623-630. <http://jxb.oxfordjournals.org/content/47/5/623.full.pdf>

[3] 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

[4] Wheeler T.R., Craufurd P.Q., Ellis R.H., Porter J. R. and Vara Prasad P.V. (2000). Temperature variability and the yield of annual crops. *Agriculture, Ecosystems and Environment*, 82, 159-167. DOI: 10.1016/S0167-8809(00)00224-3

[5] Jagadish S.V.K., Craufurd P.Q. and Wheeler T.R. (2008). Phenotyping parents of mapping populations of rice for heat tolerance during anthesis. *Crop Science* 48, 1140-1146. DOI: 10.2135/cropsci2007.10.0559

[6] Jagadish S.V.K., Cairns J., Lafitte R., Wheeler T.R., Price A.H. and Craufurd P.Q. (2010). Genetic analysis of heat tolerance at anthesis in rice. *Crop Science*, 50 (5), 1633-1641. DOI: 10.2135/cropsci2009.09.0516

Grants:

[7] Craufurd, Ellis, Summerfield, Wheeler (1995-1996) High temperature tolerance and water deficits in groundnut. Overseas Development Authority, £55,795.

[8] Wheeler (1999-2002) Felix PhD. Development of combined seasonal weather and crop productivity forecasting system. University of Reading, £75,000.

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

[10] Wheeler (2006-2007) Impact of climate variability and change on the yield and quality of rice. Royal Society India Fellowship, £69,210.

4. Details of the impact

Context

About half of the world's population eats rice daily. Climate change presents a major challenge to global rice producing regions by threatening yields, farmer livelihoods and food security. Modelling studies published in 1997 by the International Rice Research Institute (IRRI) showed that climate change could reduce Asian rice production by almost 4% by the middle of the 21st century, at a time when population growth will increase consumer demand. For example, demand for rice could increase from 524 million tonnes now to 700 million tonnes by 2025. When theoretical heat-tolerant varieties were included in the IRRI simulations, rice yields across Asia under climate change were restored to their normal levels. The research at Reading demonstrated the nature and importance of the heat stress response in rice and other crops in practice and is making theoretical heat-tolerant varieties a reality through its screening protocols.

New rice screening protocols adopted by breeders and IRRI

Rice breeders became interested in the Reading team's phenotyping protocols [5] following a presentation at a conference in Wuhan, China in 2007. The Reading protocols were subsequently incorporated into the testing procedures of the International Rice Heat Tolerance Nurseries (IRHTN) of the IRRI - a non-profit independent research and training organization located in the Philippines. The Director General of IRRI stated that "scientists at IRRI modified [Reading's] screening protocol and put it out for use by plant breeders through the International Rice High Temperature Network" [a]. The breeding team at IRHTN distributes a range of different rice accessions to all rice-producing countries across Asia and Africa. The most promising are then tested for heat tolerance using a simplified version of the Reading screening protocol. Evidence is provided from three example breeders in India who have adopted the new protocol [b-d].

The IRRI is also investing in an advanced breeding programme for heat tolerance based on Reading's identification of a heat tolerant rice accession (N22) in 2008. These nurseries have also confirmed the heat-tolerance trait that Reading researchers identified in a different genetic background (N22 x IR64 and others) and have tested the mapping populations for high temperature tolerance under control chambers, again using the Reading protocol.

Thus, Reading research has enabled rice breeders internationally to undertake crop selection programs so that rice growers around the world can better adapt to the temperature demands of climate change and be able to maintain or improve yields to help feed growing populations in Asia and Africa. The immediate impact of the Reading research is on the pre-breeding of rice for future climates, with ultimate benefits in the form of new rice varieties for millions of growers globally, helping to maintain yields, protect farmer livelihoods and food security.

Research informs international policy on climate change

In 2007, the Stern Review of *The Economics of Climate Change* used figures of the temperature stress effect derived from Reading's crop research data in relation to wheat and peanut varieties [e]. Although this review was published prior to 2008, it remains one of the largest and most widely known and discussed reports of its kind, and continued to be greatly influential over the 2008-2013 period, remaining a subject of debate in UK politics, e.g., [f-g].

The 2012 World Bank publication '*Turn down the heat'* includes the high temperature stress effect in the Executive Summary [h] due to the underpinning research at Reading. This document, and the Reading research, was used to support the inclusion of climate change in the top-level Sustainability Goal of the World Bank Group [i, pg 31] which has underpinned World Bank strategy and activities globally. In this way, the Reading research has contributed to the acceptance of the importance of climate change in policy agendas because of demonstration of its effects on crop yields, food security and sustainability. It has provided robust evidence to support the positions of international organisations working on climate change.

5. Sources to corroborate the impact

- [a] Letter from Director General, International Rice Research Institute (†)
- [b] Letter from Tamil Nadu Agricultural University (†)
- [c] Letter from Senior Scientist – IRRI and Rice Breeder. (†)
- [d] Contact at PAU- (*)
- [e] Stern N. (2007). *The Economics of Climate Change: The Stern Review.* Cambridge University Press < http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm>. Uses Reading research in Fig. 3.4, page 80.
- [f] HC Debate, Written Answers to Questions, 6 September 2013, vol 567, col. 569W < http://www.publications.parliament.uk/pa/cm201314/cmhansrd/cm130906/text/130906w000

2.htm#13090634000002>

[g] Ward, B. Letter to Rt Hon Peter Lilley MP. 14 December 2012.< http://www.thegwpf.org/content/uploads/2013/01/Letter-to-Peter-Lilley-14-December-2012.pdf>

[h] World Bank (2012). *Turn down the heat; why a 4^{o}C warmer world must be avoided*. The World Bank. <http://www.worldbank.org/en/news/feature/2012/11/18/Climate-change-report-warns-dramatically-warmer-world-this-century>

[i] World Bank Group (2013). The World Bank Group goals: end extreme poverty and promote shared prosperity. <http://www.worldbank.org/content/dam/Worldbank/document/WB-goals2013.pdf>

(†) Available upon request
(*) Contact details provided separately