Food and Energy Security
Open Access

ORIGINAL RESEARCH

Integrating islands of knowledge for greater synergy and efficiency in crop research

Andrew Borrell[1] & Matthew Reynolds[2]

[1]Queensland Alliance for Agriculture and Food Innovation (QAAFI), Hermitage Research Facility, University of Queensland, Warwick, Queensland 4370, Australia
[2]International Maize and Wheat Improvement Centre CIMMYT, Int. Apdo. Postal 6-641, 06600 Mexico, Mexico

Keywords
agricultural research funding, benchmarking, crop production, efficiency, focus, food security, Global Plant Council, impact pathways, integration across scales, integrators, Sustainable Development Goals, synergy, teamwork, translational research, transnational collaboration.

Correspondence
Andrew Borrell, Queensland Alliance for Agriculture and Food Innovation (QAAFI), Hermitage Research Facility, University of Queensland, Warwick, QLD 4370, Australia.
Tel: 61 7 45426740; Fax: 61 7 45426716;
E-mail: a.borrell@uq.edu.au

Received: 20 February 2017;
Accepted: 28 February 2017

Food and Energy Security **2017 6(1): 26–32**

doi: 10.1002/fes3.107

Abstract

A transnational approach to plant science is required to address global challenges such as food security and climate change. Action from the plant, crop and agricultural science communities will be required to meet these challenges. Islands of knowledge (e.g. crop, discipline, scale, environment, organization) need to be better integrated. Mapping is needed to identify gaps and make connections between these islands. Translational research, spanning from the molecular to farm scale, should be the focus. We need more `integrators' to manage complex global projects and integration should be recognized as an important skill in itself. We need to advocate teamwork over individuality - and reward teams. Impact should be taken much more seriously as an outcome and we need to better understand impact pathways. Focusing on key game-changers will more likely lead to impact rather than attempting to do everything.

Introduction

Significant challenges relating to food, nutritional, and water security in the coming decades are no longer doubted (Wiebe et al. 2016). The United Nations Sustainable Development Goals (SDGs) address the eradication of poverty and hunger along with the attainment of clean water, increased health, innovation, responsible production, climate action, and sustainable communities. Action from the plant, crop, and agricultural science communities will be required to achieve these goals. The developed and developing world face common challenges (as stated in the SDGs), common environments (e.g., rain-fed crops such as sorghum grown in northern Australia, sub-Saharan Africa, and central-western India frequently experience drought), grow common crops of interest (including maize, wheat, rice, sorghum, barley, tubers, legumes), and live on a common planet (addressing climate change is a global issue). The SDGs highlight how the developed and developing world will need to work together to address these common challenges.

Meeting these challenges will require a transnational approach. For example, when comparing G20-focused priorities for wheat research (www.wheatinitiative.org) with those of less developed countries served by the Consultative Group for International Agricultural Research (CGIAR, www.cgiar.org), 80% of the traits identified are common (www.wheat.org), providing obvious opportunities for international collaboration. While single crop-focused research still achieves economically significant genetic gains,

given the transnational nature of many agricultural problems, it is generally accepted that crop scientists will need to work across borders to maintain global food security. Crop research should benefit from a more internationally oriented approach to achieve better leverage of technology, expertise, and infrastructure (Reynolds et al. 2016).

Important outcomes have already been achieved in less-developed countries through their national agricultural research programs in collaboration with international entities such as the CGIAR, the Bill and Melinda Gates Foundation (www.gatesfoundation.org), and various advanced research institutes. These collaborations can be further developed by fostering an environment where productivity constraints of a transnational nature are routinely investigated from a global perspective, integrating research across crops and agro-ecosystems, with routine sharing of data and other resources. Some potential actions over a range of timescales (short, medium, and long term) will be discussed in this study.

Integrating Islands of Knowledge

Funders of agricultural research frequently favor novel or exciting ideas without considering how outputs may link to previous or parallel projects, creating islands of relatively isolated knowledge. An effort to map islands of knowledge could help identify productive synergies. Examples of islands are disciplines, crops, environments, scales, organizations, or major projects (Fig. 1). It is important to define (or recognize) islands in order to identify opportunities to build bridges among relatively isolated research thrusts using comparative biology (e.g., Valluru et al. 2015), translational research linking upstream work to solve productivity problems, interdisciplinary approaches, and integration across biological scales (e.g., Passioura 2010).

Prioritization of investments by funding agencies on the basis of linkage, rather than funding a new island of knowledge, would be a valuable criterion when evaluating research proposals. At the very least, if a new island is funded – then funders need to make sure it is linked to other islands of knowledge. Funding agencies could consider investing in linkages to achieve synergy, rather than speculating on novelty, single-discipline approaches, or projects with limited scale. Rather than expecting automatic outcomes from relatively specialized teams, impacts will be more likely if all appropriately qualified groups are funded considering comparative advantage.

Focus and Integration

To be most effective, we also need to strike a balance between focus (or reductionism) and integration. Linkages can be made between focused projects by reviewing outputs at regular intervals to identify pertinent linkages. For example, projects should consider the immediate level of integration above and below the focus of the project (Passioura 2010). This would go a long way to opening opportunities for sharing concepts and technologies between different levels of integration from within the same discipline. In this context, a research team studying drought adaptation in cereals at the organ level (e.g., leaf growth) should integrate their findings 'up' a scale to the whole plant level and 'down' a scale to the tissue level, thereby better understanding how leaf dynamics fit into a larger framework (Fig. 2). This approach should also encourage scientists to collaborate across scales (e.g., molecular biologists, biochemists, plant physiologists, crop physiologists, agronomists, and plant breeders) to achieve both increased understanding and greater impact.

Similarly for work in model species that is funded on the basis of its translational potential, confirmation that mechanisms and genes can be extrapolated to crops should be sought at the earliest opportunity, certainly before 'exciting' results – that may not in fact be relevant to productivity constraints – cause researchers to go off on

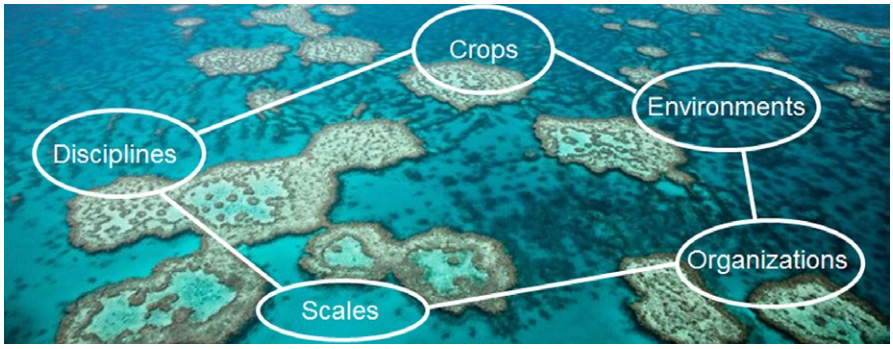

Figure 1. Building bridges between islands of knowledge should enhance the impact of global research addressing food security (background image from www.world.time.com).

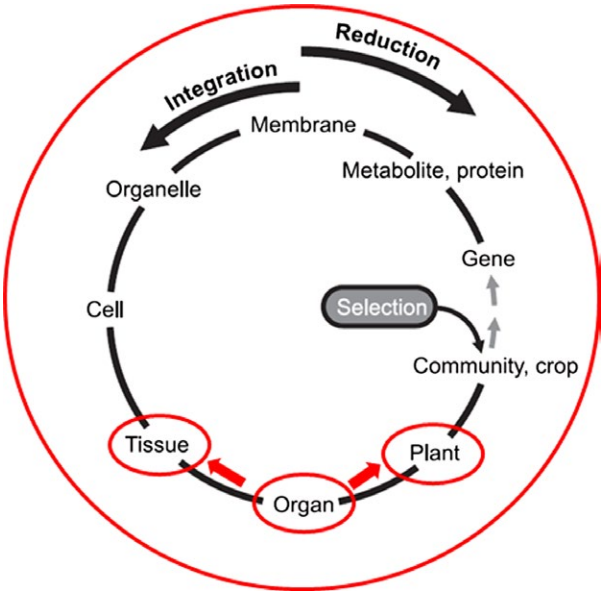

Figure 2. Modified from Figure 1 in Passioura (2010). Levels of organization in crop plants, represented as a loop in which clockwise flow represents reduction, the search for mechanistic understanding at finer and finer scales, whereas anticlockwise flow represents functional integration, the roles of various structures and processes in transmitting genes to the next generation. In the sense that selection of individual genotypes at the crop level (or, in natural systems, the community) determines the genetic makeup of the next generation, the 'loop' is a helix when viewed across generations.

costly tangents. The importance of this point is underscored by the generally poor association found between field and controlled environments (Poorter et al. 2016).

However, to achieve integration, rather than having large unmanageable projects with substantial transaction costs, the scientific community should identify and support bigger-picture thinkers who have the appropriate breadth of experience to identify ways to integrate outputs of projects. We need to invest specifically in the integrators. While in theory, research directors and managers have this role, in practice time for such 'big-picture' observation and thinking is eroded by ever increasing transaction costs associated mainly with administrative compliance and more restrictive funding opportunities. Furthermore, integration should be recognized as an important skill in itself, and all individuals should be encouraged to highlight their work in the broader context, and to promote better communication and understanding of the bigger picture.

Recognizing Teams

We need to promote team effort rather than individual achievement. This will be facilitated by less hierarchical models in favor of team evaluation and multisource assessments. While authorship of scientific publications does highlight a trend from single or few authors per paper 30 years ago, to many authors per paper now, we still have a way to go. Unfortunately, many of the accolades in science go to the individual rather than the team. This does not mean that such accolades are not worthwhile – indeed they do recognize great achievement and they do put science in the spotlight. Nonetheless, we need to recognize the importance of team dynamics as well.

It is important to recognize the value of all disciplines in each context rather than considering one discipline as inherently more valuable or 'scientific'.

Impact is Important

Impact, as well as publication record, should be taken much more seriously as an outcome of research. The magnitude of impact is generally related to the degree of integration of a research study and the extent to which islands of knowledge are linked; however, impact does not always just happen. Careful planning, adequate resourcing and precision in execution will all help to enhance the usefulness of any data collected. From the outset, transnational scientific endeavors which actually target enhanced food security (not just high-quality plant science) should strategically plan a clear pathway to impact. Often, focusing on a few key game changers will result in greater impact than attempting to do everything. The planning process should include benchmarking, identifying strategic goals for crop improvement and management, and developing a detailed project plan. In bilateral partnerships, pairing of researchers (one from each country) from common disciplines (breeding, physiology, modeling, information technology, etc.) can work well in this planning process. Breaking down barriers enhances impact.

Benchmarking – Beginning with the End in Mind

Benchmarking is a fundamental component of planning transnational collaborations. In crop improvement programs, data should be collected and collated to provide a detailed description of the starting point. All progress at the end of the project should be assessed relative to this initial benchmark, enabling impact to be objectively assessed. Greater clarity can be achieved by benchmarking individual components of crop improvement programs (e.g., breeding, physiology, grain quality, information technology, modeling, etc.), and can help identify where disciplines or expertise are missing.

Successful National and International Collaborations as Case Studies

Global wheat partnerships

There are some good examples of agricultural science collaborations at the national and international levels, including successful multilateral and bilateral partnerships, and potential benefits of more global integration of agricultural research have been documented (Reynolds et al. 2012). At the international level, the CGIAR now supports a number of collaborative approaches. Networks for disseminating and evaluating new wheat germplasm, for example, emerged in the Green Revolution (Braun et al. 2010), and continue to this day (Fig. 3). Now with modern GIS tools, greater precision of data collection is possible and statistical and simulation models can be used to effectively interpret such databases (Lobell et al. 2011; Gourdji et al. 2012).

A good example of an effective international partnership is the International Wheat Improvement Network (IWIN), which embraces a global collaboration of wheat scientists testing approximately 1000 new well-adapted, disease-resistant wheat lines each year at over 700 field sites. Breeding is directed toward 12 different megaenvironments, representing a range of temperature, moisture, and disease profiles as described in Braun et al. (2010), based on up-to-date GIS and economic information (Gbegbelegbe et al. 2017). As well as testing widely for yield and adaptive phenology, in Kenya, for example, wheat lines are screened for a new and highly virulent stem-rust fungus, in a systematic effort to avert a devastating pandemic (Singh et al. 2011). Also, in partnership with CGIAR, the International Wheat Yield Partnership (IWYP) utilizes a research platform in a region of high wheat productivity in Mexico, where outputs of basic research from IWYP's international projects can be tested and translated into breeding products before being distributed internationally via the network. The IWIN has resulted in massive phenotypic datasets (Braun et al. 2010; Gourdji et al. 2012) and delivered germplasm that is estimated to be worth several billion dollars in extraproductivity to hundreds of millions of farmers in less-developed countries, annually (Pingali 2012), and by raising yields has saved more than 20 Mha of land from being brought under cultivation (Stevenson et al. 2015).

Translating photosynthesis research from laboratory to field

At the national level, the Australian Research Council (ARC) has recently funded a 7-year Centre of Excellence for Translational Photosynthesis (CoETP; http://photosynthesis.org.au/). This venture is designed to integrate islands of knowledge through multiorganizational (ARC, The Australian National University, The University of Queensland, Western Sydney University, The University of Sydney, CSIRO and International Rice Research Institute), interdisciplinary (plant breeding, crop physiology, genomics, molecular biology, biochemistry, engineering, bioinformatics, and simulation modeling), multiscale (subcell, cell, organ, whole plant, crop), and translational

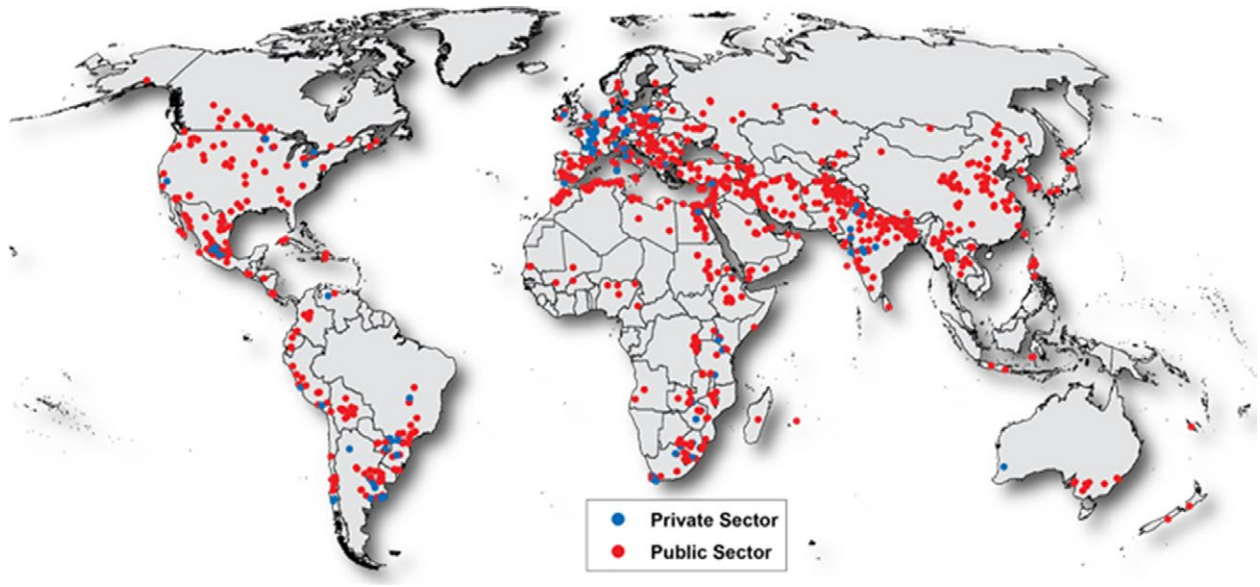

Figure 3. Testing sites of the International Wheat Improvement Network (IWIN).

(spanning molecular to farm levels) approaches. The Centre brings together researchers to tackle one of the grand challenges facing humanity – feeding more people with less resources in the face of climate change. Photosynthesis is the most important biological process to have arisen in the evolution of the Earth, producing the oxygen we breathe, the food we eat, and the climate we live in today (http://photosynthesis.org.au/; Hohmann-Marriott and Blankenship 2011). Improving photosynthesis is now recognized as the new frontier for increasing crop yields (Long and Ort 2010; Zhu et al. 2010; Ainsworth et al. 2012).

The aim of the Centre is to contribute to the development of new crop varieties that are more productive than existing strains, particularly in wheat, rice, and sorghum. This includes varieties that produce high yields of grain in conditions of less water, higher temperature, and higher concentrations of carbon dioxide in the atmosphere. By improving the ability of major food plants to convert sunlight, air, and water into leaf and seed production through photosynthesis, the Centre can contribute to a new yield revolution for food crops. The key word is *translational* – taking scientific discoveries from the laboratory and translating them to useful yield outcomes in the field. It is early days yet – but there is already a palpable sense of excitement about the opportunities and potential outcomes arising from the synergies created in this project.

Increasing the rate of genetic gain for sorghum in sub-Saharan Africa

Successful bilateral partnerships highlight the capacity to combine focus and integration. An example of this is a partnership between the Ethiopian Institute of Agricultural Research (EIAR, Ethiopia) and the University of Queensland (UQ, Australia) funded by the Bill and Melinda Gates Foundation and the Australian Centre for International Agricultural Research (ACIAR). The project addresses food security issues in sub-Saharan Africa by seeking an enduring increase and stability in productivity of sorghum in water-limited production systems through the development of more effective local crop improvement programs. The partnership is outcome driven, focused on strategic step changes, yet aware of the big picture. This project is an example of linking islands of knowledge in terms of disciplines (plant breeding, crop physiology, simulation modeling, bioinformatics), environments (low, mid, and high altitude), scales (organ, plant, crop), and organizations (EIAR, UQ, various Ethiopian universities).

One key insight driving this project is the importance of focusing on a few key game changers, rather than trying to do everything. As this partnership is modeled on the Australian Sorghum Improvement Program, the key game changers were identified by experienced scientists who were able to pick likely winners (Hammer and Jordan 2007). A logical framework was used to dissect the rate of genetic gain, identifying where the greatest returns on investment could be achieved. Some of the game changers proved to be relatively simple, yet profoundly impacted outcomes. For example, the concept of partial replication was introduced to increase the number of genotypes that could be evaluated, smart phones replaced hand-written field-books to revolutionize data capture, and bar codes automated field measurements and seed processing. Linking these technologies has the capacity to significantly enhance the rate of genetic gain in EIAR's sorghum breeding program.

Actions to Increase Synergy and Efficiency in Crop Research

Short term

A key role for the Global Plant Council (GPC) (http://globalplantcouncil.org/) could be to map islands of knowledge to help identify productive synergies. It would be important to develop an inventory of investments in crop research internationally, in order to identify gaps that may be filled with opportunities in comparative biology, translational research, and other interdisciplinary approaches. GPC could do some research on what interdisciplinary models have been most effective in achieving real-life outcomes from agricultural R&D, and then make recommendations to the donor community on more effective deployment of funding strategies. This research could also include economic analysis.

The role of integrators needs to be further investigated. GPC could explore how integrators are a catalyst for creativity by stimulating innovation at the interface between various disciplines, crops, institutions, environments, and scales. GPC could also consider how research organizations and funders might better recognize and invest in integrators.

Short-medium term

Global Plant Council could recommend that funding agencies prioritize investments on the basis of linkage, rather than funding new islands of knowledge. In other words, funding models should consider integration and interdisciplinary approaches over 'magic bullet` type approaches which tend to encourage the opportunist approach over scientific rigor. The GPC blog could list and highlight work/projects/articles that explicitly

demonstrate integration of disciplines and synergistic approaches that are outcome and impact oriented. GPC could assist funding agencies in defining and identifying islands using the inventory mentioned above, and propose mechanisms for integration to create synergies and increase efficiencies.

The balance between focus and integration, and the concept of integrating across levels, are worthy of more consideration. GPC could play a role in further understanding integration across levels.

Global Plant Council could have an advocacy role with journals and funding bodies to encourage approaches (aims and scopes, special issues, calls, etc.) that showcase multidisciplinary and outcome-focused work. GPC could also nurture this agenda with groups of young people, high schools, undergraduate groups, etc. It would be beneficial to take advantage of recognized leaders to inspire a new generation to think about the broader context of disciplinary efforts and integration; concept papers or newspaper and magazine articles could also be written about integrative approaches. GPC could also facilitate access to:

- Platforms to share tools and encourage the sharing of resources such as manuals, methods, links to tried and tested manufacturers of technologies, etc.
- Shared intellectual property, for example, through "patent pools" to encourage crosslinkages.
- Long-term and/or multilocation experiments can provide excellent platforms for integration. Rothamsted provides a good example in the Broadbalk experiment which started in 1843.
- Crop-related models that help integration of disciplines and make use of islands of knowledge.
- Other "linking" technologies such as genome resources that link trait biology with breeding data, and phenotyping approaches that are applicable across many environments, crops, etc.
- Crop modeling is an area that depends on interdisciplinary linkage and would achieve much greater impacts as a result of many of the suggestions made herein, including shared data platforms, common research standards, and multilocation and other comparative research approaches.

Medium term

Global Plant Council could investigate models that favor teamwork over individuality. What are the benefits of teamwork? How do we reward teams? How do we sell the merits of team research compared with individualism? There are definite synergies arising from well-integrated team research. For example, some individuals are more likely to publish better science and have greater impact if they are part of a well-integrated team rather than operating in isolation.

Long term

Impact should be taken much more seriously as an outcome. Many organizations and funders focus on publications and citations more than impact. In the face of significant global challenges such as food security, resource scarcity, and climate change, we need scientists to actually apply what has been documented in papers. This is not an either/or scenario. Impact and publications should go hand-in-hand. They are not mutually exclusive. There could be a role for GPC to explore how R&D impacts major global issues around crop production – with a focus on impact. GPC could also do some research on impact pathways, identifying the key steps required to enhance impact and outcomes. GPC can try to promote a 'culture change' in crop research away from speculating on novelty and emphasizing a particular discipline because it is in vogue in favor of integration, problem solving, and favorable outcomes for humanity. Finally, to enable impact to be taken more seriously and implemented cost effectively, GPC could encourage organizations and funders to think more about measurement and metrics at the start of a project, rather than acting retrospectively.

Conclusions

A transnational approach to plant science is required to address global challenges such as food security and climate change. Islands of knowledge (crop, discipline, scale, environment, organization, etc.) need to be better integrated. Mapping is needed to identify gaps and make connections between these islands. Translational research, spanning from the molecular to farm scale, should be the focus. We need more 'integrators' to manage complex global projects and integration should be recognized as an important skill in itself. We need to advocate teamwork over individuality – and reward teams. Impact should be taken much more seriously as an outcome and we need to better understand impact pathways. Focusing on key game changers will more likely lead to impact rather than attempting to do everything. There is a role for the Global Plant Council to facilitate and empower the changes required to bring about greater synergy and efficiency in crop research worldwide.

Acknowledgments

This paper is based on outcomes from a Stress Resilience Symposium held in Brazil in October 2015 organized by the Global Plant Council and Society for Experimental Biology. The authors would like to thank the Society of Experimental Biology for funding support for this symposium.

Conflict of Interest

None declared.

References

Ainsworth, E. A., C. R. Yendrek, S. Sitch, W. J. Collins, and L. D. Emberson. 2012. The effects of tropospheric ozone on net primary productivity and implications for climate change. Annu. Rev. Plant Biol. 63:637–661.

Braun, H. J., G. Atlin, and T. Payne. 2010. Multi-location testing as a tool to identify plant response to global climate change. Pp. 115–138 *in* M. P. Reynolds, ed. Climate change and crop production. CABI Climate Change Series, Oxfordshire, U.K.

Gbegbelegbe, S., D. Cammarano, S. Asseng, R. Robertson, U. Chung, M. Adam, et al. 2017. Baseline simulation for global wheat production with CIMMYT Mega Environment specific cultivars. Field. Crop. Res. 202:122–135.

Gourdji, S. M., K. L. Mathews, M. P. Reynolds, J. Crossa, and D. B. Lobell. 2012. An assessment of wheat breeding gains in hot environments. Proc. R. Soc. B Biol. Sci. 280:1752–1760.

Hammer, G. L., and D. R. Jordan. 2007. An integrated systems approach to crop improvement. Chapter 5. Pp. 45–61 *in* J. H. J. Spiertz, P. C. Struik and H. H. van Laar, eds. Scale and complexity in plant systems research: gene-plant-crop relations. Springer, Netherlands.

Hohmann-Marriott, M. F., and R. E. Blankenship. 2011. Evolution of photosynthesis. Annu. Rev. Plant Biol. 62:515–548 (eds S.S. Merchant, W.R. Briggs, & D. Ort).

Lobell, D. B., M. Bänziger, C. Magorokosho, and B. Vivek. 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. doi:10.1038/nclimate1043.

Long, S. P., and D. R. Ort. 2010. More than taking the heat: crops and global change. Curr. Opin. Plant Biol. 13:241–248.

Passioura, J. B. 2010. Scaling up: the essence of effective agricultural research. Funct. Plant Biol. 37:585–591.

Pingali, P. L. 2012. Green Revolution: impacts, limits, and the path ahead. Proc. Natl Acad. Sci. USA 109:12302–12308.

Poorter, H., F. Fiorani, R. Pieruschka, T. Wojciechowski, W. H. van der Putten, M. Kleyer, et al. 2016. Pampered inside, pestered outside? Differences and similarities between plants growing in controlled conditions and in the field. New Phytol. 212:838–855.

Reynolds, M. P., J. Hellin, B. Govaerts, P. Kosina, K. Sonder, P. Hobbs, et al. 2012. Global crop improvement networks to bridge technology gaps. J. Exp. Bot. 63:1–12.

Reynolds, M. P., E. Quilligan, P. K. Aggarwal, K. C. Bansal, A. J. Cavalieri, S. C. Chapman, et al. 2016. An integrated approach to maintaining cereal productivity under climate change. Glob. Food Sec. 8:9–18.

Singh, R. P., D. P. Hodson, J. Huerta-Espino, Y. Jin, S. Bhavani, P. Njau, et al. 2011. The emergence of Ug99 races of the stem rust fungus is a threat to world wheat production. Annu. Rev. Phytopathol. 49:465–481.

Stevenson, J. R., N. Villoria, D. Byerlee, T. Kelley, and M. Maredi. 2015. Green Revolution research saved an estimated 18–27 million hectares from being brought into agricultural production. Proc. Natl Acad. Sci. USA 110:8363–8368.

Valluru, R., M. P. Reynolds, and T. Lafarge. 2015. Food security through translational biology between wheat and rice. Food Energy Secur. 4:203–218.

Wiebe, K., D. Mason-D'Croz, T. Sulser, N. Cenacchi, S. Islam, and R. Robertson. 2016. Agriculture and food security in 2050: socioeconomic and climate challenges and options. International Food Policy Research Institute (IFPRI), Washington, DC.

Zhu, X.-G., S. P. Long, and D. R. Ort. 2010. Improving photosynthetic efficiency for greater yield. Annu. Rev. Plant Biol. 61:235–261.