Association of Applied Biologists
Food and Energy Security
Open Access

ORIGINAL RESEARCH

Stress resilience in crop plants: strategic thinking to address local food production problems

William J. Davies[1] & Jean-Marcel Ribaut[2]

[1]The Lancaster Environment Centre, Lancaster University, Bailrigg, Lancaster LA1 4YQ, UK
[2]Generation Challenge Programme (GCP) c/o CIMMYT, Carretera Mexico-Veracruz, El Batan, Texcoco, Estado de Mexico, Mexico

Keywords
crop plants, local food production problems, strategic thinking, Stress resilience.

Correspondence
William J. Davies, The Lancaster Environment Centre, Lancaster University, Bailrigg, Lancaster LA1 4YQ, UK.
Tel: +44 1524 510203;
E-mail: w.davies@lancaster.ac.uk

Funding Information
The authors are grateful to the Society for Experimental Biology for financial support.

Received: 21 February 2017;
Accepted: 28 February 2017

Food and Energy Security **2017; 6(1): 12–18**

doi: 10.1002/fes3.105

Abstract

There are many ways to assess or define the stress resilience of crop production, but ultimately the resilience of systems (and communities), i.e., an ability to survive and prosper, is driven by profitability. Here we review challenges for those who seek to bring about beneficial change in practice or policy as we translate novel crop science research findings into impacts on the food supply chain. While advances in plant and crop science are relevant to this challenge, the context of application is crucial here and this will mean that many other considerations, discussed below, will potentially moderate the impact on crop growth and yield of what could be the introduction of very significant breakthroughs in genetic gain. This paper considers opportunities for plant scientists seeking to address the world's growing food security challenge by exploiting new understanding of the basis of crop stress resilience. Ultimately the local challenge is to increase the resilience of cropping systems and rural communities.

Introduction: The Challenge and a Local Response

There are many ways to assess or define the stress resilience of crop production, but ultimately the resilience of systems (and communities), i.e., an ability to survive and prosper, is driven by profitability. Here, we review challenges for those who seek to bring about beneficial change in practice or policy as we translate novel crop science research findings into impacts on the food supply chain. While advances in plant and crop science are relevant to this challenge, the context of application is crucial here and this will mean that many other considerations, discussed below, will potentially moderate the impact on crop growth and yield of what could be the introduction of very significant breakthroughs in genetic gain This paper considers opportunities for plant scientists seeking to address the world's growing food security challenge by exploiting new understanding of the basis of crop stress resilience. Ultimately the local challenge is to increase the resilience of cropping systems and rural communities.

Even though advances in plant and crop science understanding have helped us make considerable progress toward meeting the food-related Millennium Development Goals and the more recent Sustainable Development Goals, there is still a very significant "Global Food Security Challenge." This is a multidisciplinary challenge which depressingly now also involves a necessity to address the fact that for the first time in history, there are more obese people in the world than there are hungry people. We recognize that both hunger and obesity are promoting significant health problems associated with unhealthy and/or inadequate diets. While stress resilience is of less relevance to those addressing this set of issues, stress effects on crop and food quality can be appreciable and there are opportunities here for crop science to deliver change for the better.

We need to increase the availability of food in many regions of the world and also increase peoples' access to this food but the food should also be healthy. There are many social cultural and economic considerations that contribute to local differences in food availability. These considerations can be captured effectively in the following identity which describes major influences which can determine the impact of a change in a food production system:

$$G \times E \times M \times S\,(\text{Genetics} \times \text{Environment} \times \text{Management} \times \text{People/Society})$$

This interaction between a multitude of factors effectively tells us that a "local" approach to addressing many food challenges must be important. Crop science is well aware of the importance of G × E interactions in determining how effective new traits may be in particular locations/environments. Probably not surprisingly, some traits can have very positive effects on crop yield in some stress environments but the same traits can have neutral or even negative effects when environmental conditions are varied (Tardieu 2012; Bonneau et al. 2013). Often crop production is most profitable in good years (optimal conditions) and it is these profitable years that help to sustain farmers through suboptimal years when different stresses are present. Breeding for resilience, requires assessment of performance under optimal and suboptimal conditions to ensure that genetic gain under abiotic stress is not associated with a yield penalty in the absence of stress (Ribaut 2006). One of the major consequence of climate changes is the increasing unpredictability of climatic conditions and an increase in the stress intensity. As a result improved rice cultivars in some regions of south-east Asia need to be resistant to flooding during the first part of the crop cycle, but at the same time being drought tolerant as water limited conditions might occur during flowering or grain filling stages; the good news is that surprisingly those "opposite" stresses might have some common genetic basis (Fukao et al. 2011;. Rubaiyath et al. 2016*)*.

Recent work by agronomists at CSIRO (Kirkegaard and Hunt 2010) in collaboration with breeders in the same organization shows the importance of even the most basic of crop management options (M in above equation) and many other studies show that social considerations (S) are also very important in determining whether an innovation is taken up and whether it impacts on peoples' lives. Even in the most general consideration of the Food Security challenge it is apparent that peoples' access to diets dominated by poorly nutritious, often unsafe food can cause massive health problems for many. Price et al. (2013) show how novel plant stress biology implemented through genetics and crop management can have very beneficial effects on the safety of food but this crop-specific challenge requires a local "solution."

Some Targets for Plant Scientists in the Delivery of "Sustainable Intensification"

Crop scientists who focus on the interaction between the genetic basis of their crop of choice and the environment are mostly concerned with the impact of the environment (stress) on the genetic potential yield. Increasingly however we are concerned with the impact of agriculture (the crop/food production process) on the environment. There is particular concern for the overuse of the input resources required for crop production and excessive water use is a major problem on several continents, with falling water tables due to over extraction of water for irrigation having a particularly significant effect on natural vegetation and ultimately promoting desertification (Kang et al. 2008). Overuse of fertilizer impacts adversely on soil quality (e.g., Guo 2010) and on quality of ground water and surface water which can create important health risks (e.g., Campbell et al. 2016)). The stress biology at issue here is variation in water and nutrient availability and there is now much information to show how these stress variables can be exploited to the benefit of both resource use and crop production. Stress is effectively being used as a crop growth regulator. Among the best example is alternate wetting and drying irrigation (AWD) which saves water while sustaining yield and can have beneficial effects on greenhouse gas emissions and crop quality (Yang and Zhang 2010)

It goes without saying that we should seek wherever possible to minimize the damaging effects of agriculture such as those detailed above, while still seeking new ways of increasing productivity. Exploitation of understanding of the genetic basis of crop stress resilience, or how to mitigate it such as through crop diversification (Lin 2011), can be key here. International Initiatives such as the Generation Challenge Programme (GCP) have demonstrated that translational research in crop improvement is not only achievable but can be highly successful with the right combination of technical and "soft" science skills and expertise. The GCP was able to demonstrate that harnessing plant genetic diversity and applying modern biology to the development of new crop varieties that meet the needs of smallholder farmers is both an efficient and effective means of conducting translational research. This Programme promoted a way of working based on "true" partnerships by assembling the right combination of expertise into teams, by providing these teams with adequate resources- including budget- and managing their evolution toward synergy and delivery of outputs while, at the same time, encouraging and enforcing information sharing (Ribaut 2014).

Recently, the term "sustainable intensification" has been coined to describe a target for future food production methodology. This may be a useful development but most are well aware that this term is highly location-specific and even in meta-environments, techniques for sustainable use of water and nutrients in agriculture will be context-specific, depending on for example the nature of the soils and the hydrology of the region. Local "solutions" need to consider agricultural, environmental and social factors which will differ in importance, again with location and land use objective. Pollock (2016) has highlighted the fact that the preservation of viable rural communities intimately linked to local agricultural needs to be given more attention if we are to also preserve/achieve rural social stability. We will see below how crop genetics and management techniques based on understanding of the basis of crop resilience can be influential in climate-stressed communities.

Crop Science to Ameliorate the Impact of a 4 Degree World on Food Production

Projections of climate change impacts produced by a number of different modeling approaches indicate near certainty that global crop production will be negatively affected by climate change (Challinor et al. 2014). Most predictions also suggest reduced crop quality and nutritional value (i.e., decreases in leaf and grain N, protein and nutrient (Fe, Zn, Mn, Cu) concentrations) associated with warmer climates and increased CO2 levels. (Stress effects that need to be overcome).

To date, only a relatively few studies have delivered estimates of climate change effects for different regions of the world. Lobell et al. (2011) have identified South Asia and southern Africa as two regions that, in the absence of significant crop adaptation, would suffer the most negative impacts on important food crops (some of which have received little attention from stress biologists). The expectation is that future climate will be on average both warmer and wetter. Crop seasonality is affected by both the intensity and the distribution of the rains over time and both are affected by climate change (Feng et al. 2013). Increases in the inter-annual variability of yields are also likely to become more pronounced and will potentially affect stability of food availability and access (Porter et al. 2014).

Hochman et al. at CSIRO (2017) analyzed data from 50 weather stations located throughout Australia's wheat-growing areas and found that, on average, the amount of rain falling on growing crops declined by 2.8 mm per season, or 28% over 26 years, while maximum daily temperatures increased by an average of 1.05°C. By modeling these data using APSIM they calculate that the national wheat yield will fall from the recent average of 1.74 tonnes per hectare to 1.55 tonnes per hectare in 2041.

Plant science now has the capacity to develop crop varieties that are better suited to contrasting and new climatic conditions more rapidly than has previously been the case. Increases in the incidence of water deficits, chronically high temperatures and an increase generally in mean temperature can sensitively affect different stages of reproductive crop development while also accelerating crop development, resulting in shorter crop durations and reduced time to accumulate biomass and grain yield. The time from trait identification, through breeding, local availability and adoption of a new variety can be up to 30 years and although revised breeding strategies and new methodologies, such as double haploids or genomics (Varshney et al. 2012), can reduce the cycle significantly, there are many other factors that determine the adoption of new varieties by farmers. In addition to market demands that might determine profitability, new varieties require efficient regulatory processes and distribution networks and will likely be accompanied by improved management practices that enhance yield and quality potential.

Challinor et al. (2016) have identified this chain of developments through to impact as the BDA process (Breeding, Development, Adoption). These authors show that for maize in Africa both adaptation and mitigation can reduce loss of yield due to shortening cropping duration and they argue that climate projections have the potential to provide target elevated temperatures for regional breeding operations. They also stress that while options for reducing BDA time are highly context-dependent, there are common threads.

Many recent reports on the global food security challenge have stressed the need for enhanced knowledge exchange strategies in many parts of the world, including the developed world (e.g., UK Foresight). This may particularly be the case in the developing world as highlighted by Challinor et al. (2016). As many of those living in poverty in the developing world depend on agriculture for their income, vibrant agricultural systems are the key to development. The five countries in the world with the greatest problems with agricultural production and hence the greatest food and nutrition needs are all found in sub-Saharan Africa. Agricultural development can feed more people in the region and can also link to more general economic growth and reduction of poverty by generating employment. GPC (http://globalplantcouncil.org/) can help focus the attention of plant science and scientists in the developed world on this region of the developing world.

In recent years, crop yields in many African countries have begun to rise and this is early evidence, that African agriculture may now be generating its own "Green Revolution." Progress has been driven by a number of factors, including increased investment in infrastructure, introduction of policies to enhance both local and international markets, and some development of extension programs to help farmers take profit from new knowledge which can enhance crop productivity (Foresight Africa). As is the case with many aspects of food systems around the world, there is no single silver bullet which will “solve” the problem of food and nutrition insecurity. There is, however, a general view that with appropriate focus upon regional constraints, capacity development, investment and partnerships, many African countries have the potential to address the problem of substantial crop yield gaps that historically have held back development on the continent (Van Ittersum et al. 2016).

Evidence for the considerable potential of African agriculture may be found by looking at recent or intended investments by the African Development Bank. Africa currently imports one-third of all calories consumed (USD 77 Billion pa) and with widespread poverty (49% of the population in Africa lives on <USD 1.25/day) and high youth unemployment (40–60%), the imperative for an agricultural transformation that will result in broader impacts is very obvious (Chianu, 2016).

The challenges are many. Up to 60% of all famers are non-commercial or semi-commercial. Markets are underdeveloped and in many instances value chains are very weak. However, the Feed Africa Initiative has set ambitious goals for the period to 2025. It will aim to substantially eliminate extreme poverty, end hunger and malnutrition, enhance the performance of value chains in agriculture and turn Africa into a net food exporter.

To achieve these ambitious aims will require a commitment by governments and many others, especially to invest in human capital; the researchers and practitioners who will drive the development and sustainability of agricultural commodities and processes. A key challenge will be to retain the best and brightest young minds and to create a cadre of innovative scientists, including plant breeders, who see a future in African agriculture. This will not be easy. Budding young scientists often see a future in developed countries or international agencies where their talents will be well-rewarded. However, we are optimistic, the potential is there (Diop et al. 2013). We see a future where agriculture and agricultural research play an important part in national economies; where science and education will be key to economic development and resourced accordingly; and, where regional initiatives and international organizations all have a role to play in creating an enabling and rewarding environment for young African researchers.

The development of African agriculture will be both global and local; globally, the biophysical potential is huge- about 60% of the world’s un-utilized but potentially available cropland is in Africa. Locally, the vast migration of populations from rural to urban areas is creating new market opportunities.

New developments in KE with small holder farmers that might be applied globally with regional tuning have recently been described by Zhang et al. (2016). Here agronomy students from a range of regional Universities and from China Agricultural University (the project co-ordinator) are assigned to “Science and Technology Backyards” (STBs) in rural China. Often these are single villages or groups of small communities where the students work to develop farmers’ co-operatives and to introduce new technology and changed farming practice. Increases in water and nutrient use productivity and yielding that have been achieved in these villages are impressive (Zhang et al. 2016).

Campbell et al. (2016) have recently argued that given the serious threats to food security posed by climate change, attention should shift to an action-oriented research agenda. He and co-authors see four key challenges:

(a) changing the culture of research;
(b) deriving stakeholder-driven portfolios of options for farmers, communities and countries;
(c) ensuring that adaptation actions are relevant to those most vulnerable to climate change;
(d) combining adaptation and mitigation strategies.

The emphasis here is to increase stakeholder engagement in research and by definition general principles and strategies to mitigate climate change impact must be implemented at the local level. In reality the BDA catena defined by Challinor et al. (2016), also termed the research to implementation gap, or the science-policy gap, is often substantial. Action is needed to address this shortcoming and GPC may have a role to play here.

Adoption rate of technologies with the potential to reduce risks in agriculture has traditionally been slow. For example, despite a global shortage of water for most purposes, the adoption of improved water management practices has been slow, even in agriculture, where around 70% of the world’s available fresh water is used. There seems to be a clear case here for enhanced knowledge exchange between farmers, scientists and regional policy makers. How can stress resilience biology help us produce ‘more crop per drop’?

Three Examples of Possible Local Interventions to Increase Food Security, Health and Well-being at Decreasing Scale of Operation

(a) The Community Scale: Eco- and Climate-Smart Villages

Some years ago, the EU funded the development of so-called eco-villages in different regions of sub-Saharan Africa. Introduction of technological innovation on a village scale resulted in enhancement of social sustainability of the communities as a component of enhanced environmental sustainability, the importance of which was highlighted by Pollock (2016). In particular, introduction of solar arrays generated significant increases in health and well-being of children as a result of phasing out of kerosene-based lighting system and their adverse effect on air quality in the home. Energy was also used to great effect for water pumping for irrigation and deficit irrigation techniques were applied. In the Chinese STB communities described above, crop scientists have shown villagers how to grow crops with reduced nutrient and water input. Crop geneticists have also played a part.

In what appears to be a very successful collaboration between CGIAR-CCAFS and several national programmes in Africa, rural communities are encouraged to develop Climate Sensitive Villages (CSVs) as platforms where researchers, local partners, farmers' groups and policymakers collaborate to select and trial a portfolio of technologies and institutional interventions. The focus is on the objectives of climate-smart agriculture (Campbell et al. 2016): namely, enhancing productivity, incomes, climate resilience and mitigation. Importantly, context-specific objectives are established by the stakeholders.

The Campbell paper notes that a broad range of adaptation technologies are introduced into the CSVs. These include water-smart practices, weather-smart activities, nutrient-smart practices, carbon-and energy-smart practices and knowledge-smart activities, all of which have been discussed above.

(b) The Farming System Scale: Conservation Agriculture

Conservation Agriculture (CA) has been widely adopted with some success throughout the Americas, where the effects of tillage had previously resulted in loss of soil structure, soil erosion with the loss of large quantities of good quality soil. CA is said to increase yields, to improve soil fertility, reduce soil water loss, control weed growth and reduce erosion. There may also be savings on use of tractor fuel and reduced C emissions, all changes resulting in a much more stress resilient agricultural system.

However, Giller et al. (2009) have suggested that CA can leave farmers with a heavy dependence on herbicides and fertilizers. The same group has highlighted particular concerns for use of conservation agriculture in Africa. These include: decreased yields often observed with CA, increased labor requirements when herbicides are not used, an important gender shift of the labor burden to women and a lack of mulch due to poor productivity and due to the priority given to feeding of livestock with crop residues. This appears to be an excellent example of different regional manifestations of the interaction between G × E × M × S (above).

(c) The Crop Scale: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (N2Africa) http://www.n2africa.org/

Here, the crop stress which is a major problem in much of sub Saharan Africa, is a shortage of nitrogen for crops. N2Africa, a Gates-funded long term project directed by Ken Giller at Wageningen University, is focused on enabling African smallholder farmers to benefit more fully from symbiotic N2-fixation by grain legumes. The thrust of the project is a locally-focused knowledge exchange and capacity-building effort and the development of effective production technologies including inoculants and fertilizers. The capacity that is built will sustain the pipeline and deliver continuous improvement in legume production technologies tailored to local settings.

Discovery research is aimed at the identification of new elite strains of rhizobium for the several major grain legumes other than soybean – common bean, cowpea and groundnut. New elite strains will be made available to inoculant producers for scaling up the technology. The project website stresses that delivery and dissemination approaches will be tailored to local needs. New, innovative tools for monitoring and evaluation will allow "best fit technologies" to be developed at the field and farm-scale to be translated into "best-fit approaches" at the country or regional scale. In the first phase, N2Africa reached more than 230,000 farmers who evaluated and employed improved grain legume varieties, rhizobium inoculants and basal (P) fertilizers. The impact on the family of the increased utilization of legumes is particularly large as the crop is largely grown by women and used within the home.

Introduction of N fixation biology into non-legume crops may also be a game-changer if these new seeds can be made available to the very large numbers of smallholders in developing countries who can benefit from this stress resilience technology (Charpentier and Oldroyd, 2010).

It is clear from the above examples that there is much action-orientated research underway in farming communities around the world. It is equally clear that there is much still to do within the framework of the BDA pipeline (above) or the research to outcome catena. One size interventions will not "fit all" across the globe and we ask now what the Global Plant Council can do to facilitate progress in implementation as plant science and scientists seek to address a mounting number of global food challenges.

Food security is a global issue; by 2050 food production must increase by at least 60% to meet the demands of a growing population and changing diets. Meeting this challenge will require global and strategic thinking and planning. We have outlined some of the challenges to be addressed and presented examples of models that work. The key is stakeholder engagement at all levels and, in this regard, we submit that challenges for crop production will be best addressed at the local level either through the adoption and adaptation of generic solutions or through the development of local solutions through knowledge exchange and with the benefit of indigenous knowledge. There are encouraging signs that governments and regional bodies understand the importance of increasing agricultural productivity to meet the growing demands and we highlight the importance of international collaboration as a major element in increasing crop productivity and food production.

Actions for the Global Plant Council

1. Help facilitate partnerships in research to implementation projects across disciplinary boundaries and geographic borders (the right technology in the right place)
2. Help develop partnerships with international agencies
3. Promote sharing of data and working practices
4. Promote development of Knowledge Exchange resources and international training courses (novel science must be freely available to policy makers and importantly to the large numbers of practitioners producing food in the developing world)
5. Lead in the provision of advocacy for policy, practice, funding change
6. Lead in reducing the science-policy gap
7. Encourage a “bottom-up” approach to intervention
8. Lead in promoting regionally relevant interventions at a range of scales (understand the local landscape)
9. Encourage introduction of initiatives along the delivery chain.

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 for Experimental Biology for funding support for this symposium.

Conflict of Interest

None declared.

References

Bonneau, J., J. Taylor, B. Parent, et al. 2013. Multi-environment analysis and improved mapping of a yield-related QTL on chromosome 3B of wheat. Theor. Appl. Genet. 126:747–761.

Campbell, B. M., S. J. Vermeulen, P. K. Agarwal, C. Corner-Dolloff, E. Girvetz, A. M. Loboguerrero, et al., 2016. Reducing risks to food security from climate change. Global Food Sec. 11:34–43.

Challinor, A., P. Martre, S. Asseng, P. Thornton, and F. Ewert. 2014. Making the most of climate impact ensembles. Nat. Clim. Change 4:77–80.

Challinor, A. J., A. K. Koehler, J. Ramirez-Villegas, S. Whitfield, and B. Das. 2016. Current warming will reduce yields unless maize breeding and seed systems adapt immediately. Nat. Clim. Chang. 6:954–958.

Charpentier, M., and G. Oldroyd. 2010. How close are we to nitrogen fixing cereals? Curr Opin Plant Biol. 13:556–564.

Chianu, J. 2016. Technologies for African Agricultural Transformation (TAAT) International Institute for Tropical Agriculture. Available via https://issuu.com/iita/docs/bulletin_taat_2341_special

Diop, N. N., F. Okono, and J.-M. Ribaut. 2013. Evaluating human resource capacity for crop breeding in national programs in Africa and South and Southeast Asia. Creat. Educ. 4:72–81.

Feng, X., A. Porporato, and I. Rodriguez-Iturbe. 2013. Changes in rainfall seasonality in the tropics. Nature Climate Change 3:811–815.

Foresight Africa. Available at https://www.brookings.edu/research/foresight-africa-top-priorities-for-the-continent-in-2016-2/. (accessed 17 March 2017).

Fukao, T., E. Yeung, and J. Bailey-Serres. 2011. The submergence tolerance regulator SUB1A mediates crosstalk between submergence and drought tolerance in rice. Plant Cell 23:412–427.

Giller, K. E., E. Witter, M. Corbeels, and P. Tittonell. 2009. Conservation agriculture and smallholder farming in Africa: the heretics’ view. Field. Crop. Res. 114:23–34.

Guo, J. H. 2010. Significant acidification in major Chinese croplands. Science 327:1008–1010.

Hochman, Z., D. L. Gobbett, and H. Horan. 2017. Changing climate has stalled Australian wheat yields: study. The conversation, Environment + Energy. Available at https://theconversation.com/changing-climate-has-stalled-australian-wheat-yields-study-71411. (accessed 17 March 2017).

Lin, B. B. 2011. Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience 61:183–193.

Kang, S. Z., X. L. Su, L. Tong, J. H. Zhang, L. Zhang, and W. J. Davies. 2008. A warning from an ancient oasis: intensive human activities are leading to potential ecological and social catastrophe. Int. J. Sustain. Dev. World Ecol. 15:440–447, 9.

Kirkegaard, J. A., and J. R. Hunt. 2010. Increasing productivity by matching farming system management and genotype in water-limited environments. J. Exp. Bot. 61:4129–4143.

Lobell, D. B., W. Schlenker, and J. Costa-Roberts. 2011. Climate trends and global crop production since 1980. Science 333:616–620.

Pollock, C. J. 2016. Sustainable Farming: chasing a mirage? Food Energy Secur. 5:205–209.

Porter, J. R., L. Xie, J. Andrew, K. Cochrane, S. M. Howden, M. M. Iqbal, D. B. Lobell, and M. Travasso (2014) Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the. Intergovernmental Panel on Climate Change. Available via http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap7_FINAL.pdf (accessed 17 March 2017).

Price, A. H., G. J. Norton, D. E. Salt, O. Ebenhöh, A. A. Meharg, C. Meharg, M. R. Islam, R. N. Sarma, T. Dasgupta, A. M. Ismail, K. L. McNally, H. Zhang, I. C. Dodd, and W. J. Davies 2013. Alternate wetting and drying irrigation for rice in Bangladesh: is it sustainable and has plant breeding something to offer? Food Energy Secur. 2:120–129.

Ribaut, J.-M. 2006. Drought adaptation in cereals, 642 pp. Haworth's Food Products Press, New York.

Ribaut, J.-M. 2014. How to build research partnership that benefit farmers. SciDev.Net. Available at http://www.scidev.net/global/r-d/opinion/build-research-partnerships-benefit-farmers.html. (accessed 17 March 2017).

Rubaiyath, A., A. N. M. Bin Rahman, and J. Zhang. 2016. Flood and drought tolerance in rice: opposite but may coexist. Food Energy Secur. 5:76–88.

Tardieu, F. 2012. Any trait or trait-related allele can confer drought tolerance: just design the right drought scenario. J. Exp. Bot. 63:25–31.

van Ittersum, M. K., L. G. J. van Bussel, J. Wolf, P. Grassini, J. van Wart, N. Guilpart, et al. 2016. Can sub-Saharan Africa feed itself? PNAS 113:14964–14969.

Varshney, R., J.-M. Ribaut, E. S. Buckler, R. Tuberosa, J. A. Rafalski, and P. Langridge. 2012. Can genomics boost productivity of orphan crops. Nat. Biotech. 30:1172–1176.

Xue, F., A. Porporato, and I. Rodriguez-Iturbe. 2013. Changes in rainfall seasonality in the tropics. Nat. Clim. Chang. 3:811–815.

Yang, J., and J. Zhang. 2010. Crop management techniques to enhance harvest index in rice. J. Exp. Bot. 61:3177–3189.

Zhang, W., G. Cao, X. Li, H. Zhang, C. C. Wang, Q. Liu, et al. 2016. Closing yield gaps in China by empowering smallholder farmers. Nature 537:671–674.