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COMMENTARY

The case for evidence-based policy to support stress-resilient cropping systems

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Abstract

Research and the dissemination of evidence-based guidelines for best practice in crop production are fundamental for the protection of our crop yields against biotic and abiotic threats, and for meeting ambitious food production targets by 2050. The advances in knowledge required for sustaining crop productivity targets will be gained through three research tracks: (1) basic strategic research in the field, for example, crop breeding, agronomy, and advanced phenotyping; (2) translational research involving the application of advances in fundamental science; and (3) pure fundamental research to fuel future translational research. We propose that policy and funding structures need to be improved to facilitate and encourage more interactions between scientists involved in all three research tracks, and also between researchers and farmers, to improve the effectiveness of delivering improvements in crop stress resilience. History illustrates that it is challenging for public researchers to "stretch across" all of these research tracks, with effective farm-level solutions being more likely when end-users and industry are directly engaged in the research pipeline. As research proceeds from fundamental through to applied research, the demand for experimental rigor and a wider understanding of appropriate methods and outcomes is paramount, that is, demonstrating value in yield at the field level requires the input of experienced practitioners from each research track. The development of evidence-based policies to support all funding structures and the engagement of producers with both the development of research, and with the findings of such research, will form an important capability in meeting food security targets. This commentary, concentrating on the development of policies to support research and its dissemination, is based on discussions held at the Stress Resilience Symposium organized by the Global Plant Council and Society of Experimental Biology in October 2015.

Introduction

Research into the development of stress-resilient plants and cropping systems has the potential to generate significant positive, worldwide impacts for dealing with climate change and ensuring global food security. Research alone cannot bring about fundamental change; rather research findings can be used to build evidence for reaching consensus, which in turn helps to exact a change in behavior or practice through policy development. The interface between science and policy is therefore important, and it is essential that research funding and policy development should be intrinsically linked. However, this is not always the case and more needs to be done to develop effective, global, evidence-based policies for plant science.

So how do these two, often disparate, areas of science and policy interact and influence each other? In terms of the effects of science on policy, the results of well-designed scientific research can provide the evidence on which to base consensus in the scientific community. In turn, scientific consensus provides the foundation on which to build adequate and robust policies for developing and researching efficient and sustainable practices that will support crop improvement and furnish food and agricultural products to the growing human population.

Policy impacts science in many different ways; for example, it affects the level of public and private investment in both research and development, and determines the strategic priorities that direct where this investment is targeted. Institutional, governmental, and national policies also impinge on and control how research data are collected, accessed, exchanged, and stored in both the public and private sectors. Policies and regulations related to the safe use and application of technologies also have significant impacts on the agricultural sector; for example, technologies that support decision-making (e.g., satellites and drones), and/or the implementation of solutions (e.g., genetically modified organisms [GMOs], chemicals, robots).

The potential for a disconnect between the science and policy arenas becomes amplified at the international level, with governments and funding bodies around the world varying in the ways in which they decide upon and develop funding strategies and regulatory and policy frameworks. These variations exist although all nations (developed and developing) face common challenges (as stated in the Millennium Development Goals and Sustainable Development Goals (United Nations, 2015)), common environments (e.g., rain-fed crops in Australia, and sub-Saharan Africa and central-western India frequently experience drought), grow common crops of interest (e.g., maize, wheat, rice, sorghum, barley, tubers, legumes), and are all inhabitants on a common planet (combating climate change is a universal issue).

Despite these universal links, it is the national agencies and bodies that are the major funders and regulators of research. As a result, national funders – quite reasonably – place restrictions on expenditure in other jurisdictions and wish to be in control of their own regulatory frameworks. This can result in fractured – and in some cases conflicting – policies across the globe that subsequently act as a barrier to collaboration, and limit the ability to collate and share data, resources, and intellectual property across national boundaries. The end point of this is the loss of added value that can be gained from linking parallel efforts or by concentrating research in priority areas of global significance.

Given the significant impact of policy on research, from a global perspective, it is vital that policy decisions take account of global scientific consensus, and that policy decisions impacting and influencing the plant and agricultural arena be fully informed by scientific method and results from the international research community. This in turn depends – to a large extent – on scientists summarizing and explaining their work in a manner that is accessible and understandable to nonspecialist audience so that others including funders and policy makers can understand current research efforts and what comprises high-quality scientific method in different tracks of research.

Learning from Past Experience

Biotic and abiotic stresses have negative impacts on crop productivity and thus are major limiting factors to global food and nutritional security, and to the production of agricultural products. Global wheat production, for example, is projected to decrease by 6% for each degree centigrade of global warming, together with an increased variability in yield across regions and seasons (Asseng et al. 2015). Yield losses are also predicted for other major crops (e.g., Challinor et al. 2014).

One of the predictions for a changing climate is an increasing incidence of extreme weather events. In some areas this will mean more prevalent drought, heat, and/or salinity events, and research into plant tolerance to these stresses will be paramount to improve crop suitability for such conditions and mitigate stress effects on crop yield. For example, Lobell et al. (2015) revealed that while drought will continue to impact yields of wheat and sorghum in Northeast Australia, breeders will need to increase the heat tolerance of these crops to mitigate the damage from increasing frequencies of extreme heat stress events in this region. Such research topics are not new endeavors, and the lessons learned from previous and current research can inform us how new policies might best support the development of stress-resilient cropping systems (Gilliham et al. 2017).

For instance, from the outcomes of previous research on drought and salinity research it is clear that tolerance to these stresses is complex requiring multiple traits, with tolerance to each stress composed of multiple traits (e.g., for salinity; exclusion of salt from the shoot, stomatal closure, detoxification of reactive oxygen species, the adaptation to low water potential in the soil); some of these traits are required for tolerance to both stresses (Chaves et al. 2009; Huang et al. 2009; Munns and Gilliham 2015). In extreme circumstances, crops can face multiple threats at the same time, for example, low water availability, high salinity, high temperatures and biological pests; therefore, crops must be well adapted to multiple threats.

Tolerance to abiotic stress requires both consideration of the crop's genetics (and its capacity to respond to the environment), and the best crop management to mitigate the impact of a stress. A holistic approach is needed whereby multiple research angles are deployed and integrated to achieve the best results, encompassing genetics, breeding, physiology, predictive modeling, agronomy, and extension to growers (Hammer et al. 2016). In combination, these approaches have led to research impact through translation in both the private and public sector, but have required a substantial cross-scale effort for delivery (Gilliham et al. 2017).

One such challenge is the agronomic management of water throughout the season. While it is sometimes viewed as an extension rather than a research challenge, new technologies have the potential to transform water management in agriculture (e.g., smart weather sensing and modeling for irrigation scheduling, or biodegradable plastic mulches; Clawson and Blad 1981; Lebourgeois et al. 2009; Li et al. 2013). In dry environments, the adoption of no-tillage systems has been a major factor in increasing soil organic matter by protecting it from erosion, and in conserving soil water through the season across much of the world's agricultural lands (Derpsch et al. 2010). These systems typically require mechanized management augmented by the careful use of biodegradable herbicides so that weeds do not develop resistance to chemical control. In addition to policies encouraging the use of these techniques, the development of herbicide-tolerant varieties (usually, but not necessarily, GMO) has facilitated the rapid adoption of no-till, especially in South America. Herbicide-tolerant GMO varieties have therefore had a significant impact on yield in dryland environments by encouraging the adoption of no-till and its water-conserving benefits.

There has been considerable investment in molecular and laboratory-based solutions to stress tolerance. These investments include the use of sequencing technologies, the deployment of molecular markers, "speed breeding", and – to a limited extent – genetic modification. GMOs (for herbicide and insect tolerance) have made substantial contributions to increased food production (Qaim 2009; Klümper and Qaim 2014), but genetically complex traits such as drought and salinity tolerance (much like the introduction of C4 photosynthesis into rice or nitrogen fixation into other cereals) require multigene solutions with significant lead times. These latter initiatives have received significant investment from NGOs; however, similar investment has not occurred for paradigm-shifting research in the stress resilience of cropping systems.

Assessment of impact and the evaluation of success and value can change and diverge substantially in the transition from fundamental through to applied research and to the field. This generates several challenges, particularly for research teams trying to span all levels of complexity to demonstrate and deliver new traits for stress resilience. For example, current funding and publication policies at the fundamental end of the research pipeline often require demonstration of impact, leading to numerous articles in plant journals containing statements such as "trait X has shown substantial yield improvement in glasshouse conditions". Critically, however, few of these effects will demonstrably translate to increases in yield under field conditions, despite the rigorous and repeatable demonstration of trait effects in controlled conditions. A good example of the large-sale yield monitoring technologies needed to demonstrate yield improvements in the field comes from DuPont researchers who showed a 6.9% yield advantage of highly water use-efficient corn hybrids across 2000 locations (Gaffney et al. 2015). We do not propose that such extensive approaches are required to demonstrate the value of potential new traits in the early part of discovery; rather that statements about "yield" require a rigorous evidence base, careful consideration of alternative hypotheses for the observed results, and a clear appreciation of the likelihood of the trait having an impact in the field, before inclusion in publications. For example, a yield increase of 50% is highly unlikely at a field level except in very specific circumstances. When such observations are included in publications, reviews, and funding policies without an appropriate field-based context, this can result in significant distortions in policy and investment strategies and outcomes.

It is important that fundamental research interrogating how crops survive stress is carried out so as to inform the development of new varieties. The development of water use-efficient wheat such as Drysdale, which has 10% higher yields in dry conditions, as well as the breeding of durum wheat with a 25% greater grain yield in saline conditions, were both the products of fundamental research discoveries applied to breeding programs (Rebetzke et al. 2002; Munns et al. 2012). These are good examples of why investment in both fundamental and applied solutions to stress tolerance is needed. Furthermore, investment in translational research is essential to establish the robustness of fundamental research solutions prior to their implementation in farming systems (Gilliham et al. 2017). It should also be noted that these are long-term investments; it took 20 years for Drysdale to be released following elucidation of the trait underlying its increased water use efficiency.

To most effectively deploy research aimed at improving the stress resilience of cropping systems, an integrated science, policy, and society approach is needed to ensure that disparate skillsets and expertise come together. Although it is not exclusively the case, scientists who perform most of their stress tolerance research in the laboratory, and those based primarily in the field, operate in different arenas and rarely interact or combine efforts. The involvement of primary producers in research strategy or projects can also be lacking. Future research cannot afford to ignore the potential synergies gained by involving all three stakeholders. Examples of projects that have benefited from broad involvement include those listed above, that is, the development of water use-efficient wheat or salt-tolerant durum wheat, but more are needed. Unfortunately, funding is a currently one barrier to progress in this area. Few funding structures can take on promising advances made in fundamental science, validate them, and assess whether they can be translated into the yield gains in the field (Gilliham et al., 2017). A recent report by the Australian Academy of Science identified a specific fund for translational science as a key priority for the future (Australian Academy of Sciences, 2017).

Funding is not the only issue. Stress-tolerance traits related to survival identified in laboratory-based studies are often not relevant for maintaining yield in the field (e.g., Chapman et al. 2002; Hammer et al. 2016); therefore, policies must be created to fund structures that work toward applying, translating, and researching yield improvement in the field over the mid-to-long-term (Gilliham et al., 2016). This is another reason why encouraging entities that have not commonly worked together (e.g., laboratory-based fundamental scientists and field-based researchers) to join forces is important to ensure that traits relevant to stress resilience in the field are examined and rigorous translational studies are conducted. The private sector designs research flows to ensure that links between research tracks function to deliver improved germplasm, but these are more challenging to develop within the public sector research system. Policy that encourages public–private partnerships is increasingly utilized in sponsoring agronomy research, but less so in plant breeding.

A more detailed assessment of traits relevant to stress tolerance in the field can be found elsewhere and are often informed by predictive modeling of agricultural systems (e.g., Cooper et al. 2014; *Hammer* et al. 2016). Borrell & Reynolds (2017) discuss the need to join and maximize islands of isolated knowledge to maximize potential outcomes. This applies to both isolated concurrent research being conducted on similar topics through forming effective collaborations. A balance needs to be struck to avoid "tipping the scales" and creating situations in which new initiatives are funded at the expense of pure fundamental research that feeds the innovations of tomorrow, or purely field-based studies that inform practice and lead to important gains.

The Bigger Picture

For multifactorial traits such as drought and salinity tolerance, research investment and policy decisions must take a "big picture" approach ranging from the gene, to the field, to the ecosystem level, to develop crops and cropping systems that will meet future needs. Such a holistic approach will require the intelligent use of "big data," and the development of new technologies to support research studies and the application of research findings in the field.

Agriculture, like many other areas, is undergoing a data revolution; examples range from real-time monitoring of livestock health and condition; automated glasshouse control of vegetable quality; and the application of satellites, unmanned aerial vehicles (drones), machine yield monitors, and farmer information crowdsourcing platforms. These new technologies and associated data generate a wealth of opportunities for new discoveries and innovative solutions, but at the same time create numerous challenges for policy development.

There is growing pressure from governments and funders across the globe to make public data more open and accessible. However, what open data mean in practice, and how it will contribute toward increasing food security, improving human health and nutrition, and ensuring the more sustainable management of natural resources, is still being assessed and the associated policies are in development. For example, how do you balance "data ownership" – which may encourage business development and competition – with the concept of "open data?"

Initiatives such as Global Open Data for Agriculture and Nutrition (GODAN) are grappling with this and many other issues associated with the open data concept. GODAN supports the proactive sharing of open data to deal with the urgent challenge of ensuring world food security. By bringing national governments together with nongovernmental, international, and private sector organizations, GODAN seeks to support global efforts to make agricultural and nutritionally relevant data available, accessible, and usable for unrestricted use worldwide. The initiative focuses on building high-level policy and public and private institutional support for open data. The existence and popularity of GODAN (450 partners) illustrates how far-reaching the issue of open data is, and that if progress is to be made, solutions and policies must be developed and adopted at a global scale.

For policies to truly have maximum impact, the conversation must move beyond the science and governance arena. Widening the conversation to the broader global community is therefore vital, but does require initiatives to train, equip, and encourage scientists and science communicators to engage members of the public with research of broader media interest. Although many scientists are well trained to perform their laboratory or field-based research, they often lack the skills required to communicate their research and its implications to a general audience in an easily accessible and approachable manner. Several organizations and programs across the globe provide training in communication and outreach; for example, Sense About Science, a UK-based charity with new EU and US-based counterparts, has established the Plant Science Panel, a group of expert plant scientists that answers questions (online) posed by members of the public to help promote understanding and address misconceptions on any plant science-related topic. The same charity has also set up the Voices of Young Science network, and an associated series of successful "Standing up for Science" workshops across the UK, that helps to better equip early career scientists to talk about their research, and provides advice on how to get involved in discussions in the public arena. Projects like this are essential to help provide researchers with the skills, confidence, and opportunities to contribute to science and policy-based discussions.

Forming evidence-based policies that will have the greatest impact will require a full consideration of all viewpoints and surrounding issues. Policies cannot be developed, much less implemented, unless there is consensus, and consensus cannot be reached without being fully informed of the research, funding, and policy landscape. Developing an informed "community" requires effective communication between all stakeholders. Such a dialog should take place in an international context and involve not just those embedded in the research, policy, and regulatory arenas but also the wider public.

Actions

Trying to help bridge the gap between science and policy is logistically, culturally, and politically challenging but, as has been demonstrated with "big issues" such as climate change and the work of the Intergovernmental Panel on Climate Change, it is possible. The question is: can the plant/agricultural community develop a similar global effort?

As a global organization with members across six continents, the Global Plant Council (GPC) (http://globalplantcouncil.org/) is well placed to help facilitate better integration between the research, funding, regulatory, and policy domains, as outlined by the mechanisms proposed below.

Building consensus view

Short term

- Develop an understanding of the current landscape by:

  a. Gathering evidence on the current scientific consensus regarding what is required at the international level to develop stress-resilient crops and cropping systems; for example, reports, papers, and position statements.
  b. Collating information on current projects across the globe and,
  c. On current regulatory frameworks of relevance to stress resilience research.

- Assess current community needs by:

  d. Undertaking electronic survey(s) of the GPC's membership, and the wider community, to understand the major bottlenecks to developing stress-resilient crops and cropping systems with respect to policy and regulatory frameworks.

Medium term

- Help build a consensus by:

  a. Developing position statements based on the findings of the landscape study and survey of needs.
  b. Working with other key organizations to develop international consensuses, taking key political issues into account, which outline current bottlenecks and potential solutions to improving the policy environment of relevance to developing stress-resilient crops and cropping systems.

Long term

- Advocate for the inclusion and implementation of scientific consensus in international policy and regulatory frameworks.
- Advise international bodies, funders, and other forums to inform funding, regulatory, and policy decisions.

Developing an informed community – promoting a global conversation

Short term

- Exchange research and policy knowledge by:

  a. Using the GPC's social media channels to help those working on similar topics in the areas of stress-resilient crops and cropping systems to become more aware of each other's efforts and activities.
  b. Raising awareness of current open access and data-sharing policies, as well as examples of appropriate and inappropriate experimental methods in different research tracks.
  c. Generating an online database of the information gathered in the landscape study.

Short-to-medium term

- Develop viewpoint articles from a range of stakeholders on the current challenges and solutions in building adequate and robust frameworks at the science/policy interface.

- Publicize these articles via social and traditional media, with accompanying, engaging materials (e.g., videos, leaflets, case studies) to raise awareness of global issues in local contexts, and start a conversation with the public, stakeholders, and politicians.

Medium-to-long term

- Collate articles and viewpoints into an annual online publication.

Training a new generation of plant science communicators to "stand up" for evidence-based policies

Short term

- Collate information about existing science communication and science policy courses and advertise them to a wider audience.
- Provide discussion points about what constitutes rigor in demonstrating physiological (to scientists and funders) and field-level (to farmers) value of stress resilience research

Longer term

- Work with others to assess which approaches and courses are productive/successful, and for which audiences (school, community group, government, international). Based on this, the GPC could help to develop future online courses (e.g., massive open online courses) to enthuse and inspire a new generation of communicators.

Establishing consensus is the first step toward realizing effective, global, evidence-based policies for plant science and allied research and development. If multiple, diverse stakeholders from around the world can be brought together under the banner of a single, global organization, such as the Global Plant Council, then our combined voices will be much louder.

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Conflict of Interest

The authors of this article are either affiliated to the Global Plant Council through membership of their Society or are employed by the Global Plant Council.

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