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PERSPECTIVE

The Global Plant Council: Increasing the Impact of Plant Research to Meet Global Challenges

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Fig. 1. Founding members of the Global Plant Council at the 2009 Summit Meeting convened by the American Society of Plant Biologists. Front row from left: Mel Oliver (ASPB), Sarah M. Assmann (ASPB), Carl Douglas (CSPP), Zhihong Xu (CSPB), Crispin Taylor (ASPB), Christine Foyer (FESPB).
Middle row from left: Ariel Orellana (CNNPB), Suk-Ha Lee (ICSS), Karen Metzlaff (EPSO), Shahrokh Khanizadeh (Plant Canada), Jorge Vázquez-Ramos (SMDB), Eligio Morandi (SAFV), Zuhua He (CSPB), Kasem Zaki Ahmed (ACSS).
Back row from left: Barry Pogson (ASPS), William Wiebold (CSSA), Kenneth Moore (ASA), Wilhelm Gruissem (EPSO), Tom Hamborg Nielsen (SPPS), Tuan-hua David Ho (ASPB), Kenzo Nakamura (JSPP). Not shown: Hong Keun Choi (KSPB).

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As we write this perspective on the Global Plant Council, the newly formed and registered, not-for-profit organization of national plant and crop societies from around the world, the United Nations Organization (UNO) and the Food and Agricultural Organization (FAO) are calling upon the USA to reduce its use of corn for bioethanol production and make it available for feeding humans and animals (http://www.bbc.co.uk/news/business-19213550). The USA is experiencing its worst drought since 1956, and the 2012 harvest is expected to be significantly lower and of poorer quality than in previous years. Farmers in Australia and India are also struggling with drought this year while floods in Brazil have crippled grain and sugarcane production. While the world continues to be concerned about the stability of the global economy, food commodity prices are surging and crop harvests are at the brink of meeting global needs. In August 2011, the World Bank reported that global food prices were at or near three-year highs and that food stocks were low and in the danger zone, making food security even more acute in developing nations. The volatility of the world food situation is not only economy-driven, but also increasingly fueled by erratic climatic conditions that impact crop yield, and increasing pressures on crops for alternative use-a perilous spiral that threatens our ability to feed the growing world population. Crop shortages and high food prices in 2008 spurred riots in many countries around the world. While the 2012 crop shortages have yet to reach a crisis level, the risks of high and volatile food prices are great and any other disaster has the potential to provoke new unrests and make farmers and poor consumers increasingly vulnerable to poverty (FAO, 2011).

The Challenge: achieving food security for the growing human population using less available resources

The dramatic growth of the human population is placing increasing constraints on agriculture and food production, a fact that is being recognized by world leaders but currently overshadowed by the crisis in global financial and industrial markets. Already today, more than one billion people are hungry and many more malnourished (http://www.fao.org/hunger/en/). Population growth, together with climate change, expanding urbanization and shifting dietary preferences will have profound and long-term impacts on food security, not only for developing countries but also for the developed world.

In 2050, less than 40 years from now, there likely will be 9.2 billion people living on this planet, 30% more than today (http://www.un.org/esa/population/unpop.htm). These people will need food and clothing, which means that food and fiber production must increase dramatically. The pressures are not purely demographic. Daily food demand per capita increased from an average of 2,360 kcal in the mid-1960s to 2,800 kcal today, while demands for high quality food such as fruit, vegetables and meat are also rising (FAO 2006). Meat production over the last 20 years has doubled (The World Bank 2008) and continues to rise in the developed world (Daniel et al. 2011) and is increasing rapidly in developing countries (Thornton 2010). Today, nearly half of the food grown worldwide is fed to farm animals in order to satisfy the growing demand for meat. Crop plants that have traditionally been used to feed humans and animals are now also used increasingly as the raw materials for chemical and biofuel production, placing previously unknown demands on agricultural production. For example, 40% of the corn grown in the USA is used for biofuel production, 40% for animal feed, and only 20% for human consumption (USDA, http://www. nass.usda.gov/Newsroom/2012/08_10_2012.asp).

Throughout agricultural history, growing food needs have been met mostly by expanding land for agricultural production, and by improving crop productivity, both genetically and through increased use of fertilizers. Almost 15 billion hectares of land are available on this planet, but only around 11% of this land is currently suitable for farming, while another 25% is used for cattle grazing (CIA 2012). Furthermore, 5 to 10 million hectares of farming land is lost annually to urbanization, deforestation, degradation and desertification (Scherr and Satya 1996; Satterthwaite et al. 2010). New land may be developed for agriculture, but it is still unclear at what cost and risk for the environment (FAO 2006). In Asia, land scarcity has already become acute in many countries, where urbanization is reducing the area available for agriculture.

Fresh water will become another important but limited commodity in the near future. During the last century, water demand around the world rose twice as fast as the rate of population growth. Agriculture today requires vast irrigated areas that account for more than 50% of total water use - a trend that is growing (UNEP 2005; Perkins 2012). Salinization and water logging of soils are frequent consequences of agricultural irrigation and poor water management, which already affect 20% of the world's irrigated agricultural land. The United Nations expects a further 20% increase in water usage for agricultural production by 2025. At the same time, projected climate change-related temperature increases threaten the reliability of water supplies in many agricultural production areas. Clearly, assuring food security under water scarcity is a formidable challenge for farmers and crop researchers (Ainsworth and Ort 2010; Fereres et al. 2011).

Until the late 1990's, agricultural production grew faster than the world population resulting in a constant increase in per capita production and low commodity prices. This was achieved mostly by technological improvements such as irrigation systems, improved seed and crop varieties, and application of fertiliser and pesticides – generally considered as the 'Green Revolution' (Kush 2001) that often came at substantial environmental costs (Hazell 2002). Although global cereal production is still rising, it is now clear that the rate of increases in yield is slowing for all cereals except maize in nearly all regions of the world (Fischer and Edmeades 2010). Consequently, with an increasing global population, agricultural production per capita is now declining. The widening gap between population growth and production shortfalls, as well as increasing demands on agricultural crops for alternative uses have seriously decreased global crop stocks all factors responsible for sharply increasing food prices. Among economic groups, the least-developed and low-income food deficit countries are the most affected by increasing and highly volatile commodity prices. There are several factors underlying the current decline in agricultural productivity, including the lack of investments in breeding new and better crops (Fischer et al. 2009).

National plant and crop societies from around the world team up to form the Global Plant Council

Scientists and world leaders are realizing that that we have little time to radically transform agriculture, work out how to grow more food on a sustainable basis without further degrading the environment, and improve our crop plants to cope with climate changes. But how can we increase the impact of plant research to address global challenges and make world leaders more aware of the important contributions that improved crop plants can make to achieve food security? In 2009, several national plant and crop science organizations from around the world (Fig. 1) met for the first time at a summit meeting convened by the American Society of Plant Biologists (ASPB) to discuss these problems and how their organizations and scientists could help by increasing the impact of plant research and raising awareness about opportunities for crop improvement and sustainable agriculture. This was the birth of the Global Plant Council, which was endorsed by the Presidents of sixteen plant science organizations and subsequently ratified by their boards and memberships.

Since then thirteen other organization have joined the Global Plant Council, which is becoming an important voice for plant scientists around the world (Table 1). During its first meeting in Montréal in 2010, hosted by the

Table 1. Global plant council member organizations

African Crop Science Society	http://www.acss.ws/
American Society of Agronomy	http://www.agronomy.org/
American Society of Plant Biologists	http://www.aspb.org
Australian Society of Plant Scientists	http://www.asps.org.au/
Botanical Society of Japan	http://bsj.or.jp
Canadian Society of Plant Physiologists	http://www.cspb-scbv.ca
Chile's National Network of Plant Biologists	http://www.biologiavegetal.cl/
Chinese Academy of Agricultural Sciences	http://www.caas.net.cn/engforcaas/index.htm
Chinese Society of Plant Biologists	http://www.cspp.cn/
Crop Science Society of America	https://www.crops.org/
Crop Science Society of Japan	http://www.cropscience.jp/e/index.html
European Plant Science Organization	http://www.epsoweb.org
Federation of European Societies of Plant Biology	http://www.fespb.org/
International Crop Science Society	http://www.intlcss.org/
Indian Society for Plant Physiology	http://www.ispp-online.org/
Japanese Society of Breeding	http://www.nacos.com/jsb/e/index_e.html
Japanese Society for Plant Cell and Molecular Biology	http://www.jspcmb.jp/english/index.html
Japanese Society of Plant Physiologists	http://www.jspp.org/eng/
Korean Society of Plant Biologists	http://www.kspb.kr/
Malaysian Society for Plant Physiology	http://www.mspp.org.my/
New Zealand Society of Plant Physiologists	http://plantbiology.science.org.nz
Plant Canada	http://plantcanada.ca/eng/default.htm
Scandinavian Plant Physiology Society	http://www.spps.kvl.dk/
Sociedade Argentina de Fisiologia Vegetal	http://www.safv.com.ar/
Sociedade Brasileira de Fisiologia Vegetal	http://www.sbfv.org.br/
Sociedade Mexicana De Bioquimica	http://www.smb.org.mx/
Sociedade Portuguesa de Fisiologia Vegetal	http://spfv.pt/default.htm
Society for Experimental Biology	http://www.sebiology.org/plant/
UK Plant Science Federation	http://www.plantsci.org.uk

Canadian Society of Plant Physiologists, the Global Plant Council established its mission, identified the pressing global problems that it will address, and solidified its organizational and operational structures. The International Association for Plant Physiology (IAPP), which represented various national plant physiology societies for over 50 years, decided in 2011 to support the mission of the Global Plant Council and merge its own activities with those of the Global Plant Council. In early 2012 the Global Plant Council became a registered not-for-profit organization. More information on the Global Plant Council, its mission, and the pressing issues that the Global Plant Council will address, can be found at http://globalplantcouncil.org/.

Issues and strategies-the Global Plant Council agenda

Current efforts focus on the development of topic areas and deployment strategies that will allow the Global Plant Council to actively participate in the global debate on world hunger, human health and wellbeing, climate change, energy and biomaterials, sustainability and environmental protection-issues that can be informed and impacted by the work and talents of the plant science community. The Global Plant Council has identified several important strategic issues that are currently being pursued with high priority, including:

- building a digital seed bank to make informed decisions on germplasm preservation and breeding strategies
- understanding the plant-environment metagenome
- better utilization and preservation of locally adapted germplasm and yield stability
- enriching agricultural diversity by promoting underutilized seed and root crops
- development of perennial crops and new crops that are more nutritious
- better understanding plants for their medicinal value
- sharing of information and resources

Clearly, these do not represent an exhaustive list of priorities, as other important issues will arise as the Global Plant Council engages plant scientists and other stakeholders in the debate and strategic research planning (for more information on pressing global problems see http://www.globalplantcouncil.org/about.htm). Discussing all key areas would exceed the space available for this Perspective, but the following examples illustrate the agenda of the Global Plant Council that require the engagement of national crop and plant societies and their scientists around the world to contribute to solutions for sustainable agricultural production to meet the food needs of the growing human population.

The Digital Seed Bank: preserving crop diversity by capturing genotype by environment interactions

Maintaining crop diversity for food security worldwide must be among the highest priorities of human society. The best estimate we have today is that our planet has around 400,000 different species of flowering plants. Since the beginning of agriculture, humans have cultivated ~7,000 plant species (http://www.fao.org/nr/cgrfa/cthemes/plants/en/), of which today only about 150 (2%) are relevant for large-scale agricultural food and fiber production. In fact, 10 plant species that are cultivated today provide over 90% of global food and feed. Agriculture today depends on only a few crops that are cultivated on a large scale, most notably the cereal crops maize, rice and wheat as well as potatoes that supply 60% of the human food energy needs. After thousands of years of breeding, these and other crops show an enormous local and environmental diversity. However, the rapid decline in crop diversity we are witnessing in modern agriculture is unprecedented and alarming, because it threatens the health of crop plants and shrinks the pool of genes that are available for future breeding programs and improvement of varieties (FAO 2010). For example, in 1982 the single rice variety “IR36” was grown on 11 million hectares in Asia. In China, all hybrid rice that is grown on 15 million hectares shares the same male sterility genes. All modern rice varieties grown around the world have the same gene that controls their dwarf growth habit. This trend in declining diversity is also observed in other crops.

Efforts are underway in germplasm banks around the world to protect crop diversity for future generations, such as storing seeds in the Svalbard Global Seed Vault that is managed by the Global Crop Diversity Trust (http://www.croptrust.org). Little is known, however, about the molecular and biochemical basis of crop diversity and how it can benefit present day varieties. More work is therefore needed to understand crop diversity and how best it can be utilized in the future by plant breeders and in molecular breeding programs to improve current varieties and develop new ones that can tolerate adverse climate conditions and defend against diseases while maintaining crop yield. This knowledge must include detailed information on the molecular and biochemical basis of genotype by environment interactions, allelic diversity, and the gene networks that control quantitative traits for yield and quality performance. The molecular characterization of crops is no longer a bottleneck, and technologies exist today for re-sequencing crop genomes at low cost. When combined with quantitative information about the expression of genes, proteins and metabolites from crops growing in environmental conditions that reflect their diversity, this will give breeders unprecedented insights that can be exploited for crop improvement programs. The

Global Plant Council will work towards complementing global germplasm preservation efforts by capturing such molecular and biochemical information in a crop Digital Seed Bank. This requires the coordination of an international effort and cooperation for selecting hundreds or thousands of varieties for characterization that represent the broadest possible span of crop diversity.

Understanding crops in their environment: the plant metagenome

Plants from the seed to the mature flowering plant continuously interact with a host of other living organisms. To improve and maintain a sustainable agricultural system, it is essential that our understanding of how plant ecosystems respond to environmental changes is accelerated. For example, most plants live symbiotically with mycorrhiza, a relationship that can significantly increase plant productivity. However, the genetic basis of this symbiotic mutualism is still poorly understood and it is unknown how climate change may impact plant-mycorrhiza interactions. Pathogenic organisms, on the other hand, increasingly threaten crop production and food security, especially when considering the rapid loss of crop diversity and shifting climate conditions. Beneficial and pathogenic organisms and the plant form a complex biological system that functions as a whole, with each component impacting all of the agricultural measures of productivity and the productive yield of the plant in terms of biomass and grain yield. This "whole plant" system has been recognized as the plant metagenome, which comprehensively describes plant-microbial-invertebrate diversity and interactions. The Global Plant Council advocates a better understanding of the complexity of organisms that constitute the plant metagenome, how plant metagenomes change in natural and agricultural systems. How these metagenomes evolve with climate change are all critical questions that must be addressed.

Making crops fit for an increasingly unpredictable climate

For agriculture to feed the growing world population we must also understand and mitigate the effects of global climate change and seasonal climatic variability on plant communities and crop yield. Ensuring optimal plasticity in crops to enable yield in marginal ecosystems and/or seasons requires an in depth understanding of the parameters controlling acclimation and adaptation to environmental perturbations in plants. This necessitates a comprehensive understanding of the nature of adaptive responses to environmental perturbations and how they are coordinated by regulatory networks. Outcomes will include insights into the relative merits of the production of elite varieties that can yield across a range of ecosystems and climates versus locally-adapted and optimized varieties.

It has been argued that the projected rise in atmospheric CO_2 could increase crop photosynthesis and yield, but this may not be realized in crops with C3 photosynthesis (Long et al. 2005). Our current understanding of photosynthesis in C4 crops and a better understanding of the gene networks controlling responses to CO_2, temperature and water availability may provide solutions to improve crops for adaptations to environmental changes (Long and Ort 2010). The Global Plant Council will work closely with scientists, breeders and farmers around the world to identify the best strategies for improving crops to better resist increasingly unpredictable climatic changes.

Food security includes the nutritional improvement of our crops

Malnutrition is a major global problem that affects nearly two billion people, resulting in massive social and economic costs to developing and developed economies (WHO 2011). Impacts include increased mortality, impaired learning, greater susceptibility to disease and infection, with consequential economic and societal impacts. Feeding these and millions of additional people a sufficient and nutritious diet in the future will require all possible tools to develop new crop varieties. Biofortification refers to the development of new and existing crops that have improved nutritional value, either via conventional agronomic breeding technologies or using genetic modification. There are a number of initiatives underway funded by a range of governmental and private organizations, including the Bill and Melinda Gates Foundation, HarvestPlus, GoldenRice.ORG, WHO and FAO, to improve the nutritional value of staple foods such as banana, rice, cassava, sorghum, wheat and maize. The Global Plant Council sees an important role in advocating the development, release and dissemination of new crops that are more nutritious so that people receive the nutrients directly from unprocessed foods. The scientific expertise of Global Plant Council members can help articulate what can be accomplished by breeding and modern molecular techniques, what can be achieved by genetic engineering, and what are the gaps in current programs. By advocating open sharing of data and information regarding biofortification efforts it can therefore increase global support and participation in current and new initiatives.

Developing perennial crops for sustainable agriculture

Maize, rice and wheat are the three major crops that require more land, water and potentially nutrients than all other crops combined. However, agricultural land, water and fertilizer resources are rapidly declining. There are also pressures to maintain yield under more variable and stress full environments. Thus, sustaining the production of maize, rice and wheat represents a considerable challenge for promoting greater environmental sustainability of agricultural ecosystems by lowering inputs (human, nutrient, energy), while maintaining yields. A possible way to achieve such a goal would be the development of perennial crops, i.e., rather than complete harvesting of the crop each season the rootstock is maintained for two or more seasons. This reduces costs and inputs for cultivation and fertilizer, ensures a rootstock deep enough to facilitate nutrient and water uptake in marginal ecosystems or seasons. Indeed, perennial versions of our crops have the potential to fix 60% more carbon per year in temperate environments, provide greater tolerance to drought (due to deep and mature root systems) and improve nitrogen use efficiency (Edward Buckler, USDA-ARS, Cornell University, personal communication).

None of the major grain crops currently in agricultural production have commercial perennial varieties. However, all have wild relatives that are perennials, and advances in genetics and breeding will enable relatively rapid breeding programs that were not possible a decade ago. The Global Plant Council will evaluate the potential of non-domesticated perennials for their development as crops and evaluate strategies to facilitate the introgression of genes for perennialism from wild-relatives into current grain crops, either via accelerated breeding or by using genetic engineering.

The Global Plant Council−an important mission for food security and a better world

The mission and agenda of the Global Plant Council are now well established. Plant scientists, breeders, national leaders, foundations and non-government organization around the world are encouraged (and will be asked) to support the initiatives and participate in the activities of the Global Plant Council. We expect that GPC and other plant science initiatives will lead to global research and development efforts towards achieving greater food security and improving human health using sustainable agricultural production systems.

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