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PERENNIAL CROPS: NEEDS, PERCEPTIONS, ESSENTIALS

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ABSTRACT

The objective of this paper is to provide an overview of the essential issues for consideration in developing perennial crops. It is not intended to be a comprehensive review, rather it seeks to highlight topics that must be addressed in order to secure a strong future for perennial crops. To do so, the paper addresses a series of questions: Why do we need to develop perennial crops. What are the challenges and opportunities they provide. How do perceptions differ in the priority to develop perennial crops. What can be done to address and change these perceptions. How advanced is development of perennial crops. Two cases are then examined: perennial wheat in Australia as a case study for a developed country, and perennial rice in Asia as a case study for a developing country. Policy implications which may arise from development of perennial crops in developed and developing countries are then considered. The paper concludes by recognizing perennial crops may serve different purposes in different situations, so their roles must be carefully articulated. The issues raised are intended to be positive, meaning the perennial crops community should react positively to address them. The publication of hard evidence in scientific journals is considered essential, along with consideration and discussion of alternative views, in order to build credibility and confidence in the case for development and adoption of perennial crops in sustainable farming systems.

Keywords: perception, policy, publication, perennial rice, perennial wheat

INTRODUCTION

This paper is the first in the FAO Expert Workshop on Perennial Crops for Food Security. The intent of this viewpoint paper is to outline the essential issues for consideration in any decision to proceed to develop perennial crops. Essentially, this paper provides a road map of key considerations: Why do we need to develop perennial crops; What are the challenges and opportunities; What are the perceptions of perennial grains; What do we need to do to change those perceptions; Where are we up to in developing perennial crops; Perennial wheat in Australia as a case study for a developed country; Perennial rice in Asia as a case study for a developing country; What are the policy implications which may arise; Where will perennial crops be grown and what are the consequences; What do we need to do next; and some overall conclusions. Consequently, the paper is intended to flag the major issues for discussion, and to draw attention to a number of contributions later in the proceedings which deal with these topics in detail. This viewpoint is not intended to be a comprehensive review; rather it seeks to highlight topics that need to be addressed in order to secure a strong future for perennial grains. The issues raised are intended to be positive, meaning the perennial grains community should seek to address them.

WHY DO WE NEED PERENNIAL GRAINS?

Global population and demand for food are increasing, while arable land is limited and faces increasing risk of degradation. To ensure food and ecosystem security, development of perennial crops could provide more options under diverse and generally more marginal conditions (Glover *et al.* 2010a,b). Perennial crops should offer more stable surface cover against soil erosion, and improved nutrient balance against soil acidification, rising water tables and salinity, thereby improving ecosystem services. Systems which include perennial crops should also offer farmers greater flexibility and diversity of enterprise, including livestock, and greater stability of income. At different scales, the result should be improved farmer livelihood, improved ecosystem services, and improved food security (see Snapp *et al.* 2014; Runck, 2014; Snapp *et al.* 2014; Van den Putten, 2014; Reganold, 2014; Leakey, 2014, this volume).

WHAT ARE THE CHALLENGES AND OPPORTUNITIES THEY PROVIDE?

To be successful, perennial crops would need to be able to regrow after normal harvest, and able to retain floret fertility and set grain, despite wide hybridization with perennial species. The progeny would require selection for agronomic type, including plant height, flowering time, seed size, and non-shattering. Appropriate resistances would be important against disease, submergence, drought and soil constraints, depending on the characteristics of the target environment. Finally, the successful perennial crop would need to be compatible with its farming system (see Hayes *et al.* 2014; Bell, 2014; Dost, 2014, this volume).

HOW DO PERCEPTIONS DIFFER ON THE PRIORITY TO DEVELOP PERENNIAL GRAINS?

While we can see the benefits, many see problems, at least initially. The genetic challenges in wide crosses are complex, with reports of low seed set in amphiploids capable of regrowth after harvest (Cox *et al.* 2002). Consequently, some have dismissed prospects for the development of perennial crops as just too difficult.

Developed countries have expressed several concerns about potential threats to their established annual crops from perennial relatives. Given perennial species often have robust rhizomes, concern has been expressed that perennial crops may possess potential to become serious weeds, via hard-to-kill rhizomes. Many have been concerned with the possibility of the perennial providing a “green bridge” for disease, via the availability of living tissue able to propagate additional generations of disease, thereby increasing inoculum availability early in the season, encouraging earlier infection and increased risk of epidemics. These extra cycles of disease could enhance probabilities for mutations to bypass current plant resistance, thereby reducing the longevity of resistant cultivars. Finally, wide crosses are likely to result in shattering, small grains and reduced grain quality, necessitating separation of perennial grains from others, perhaps consigning them to feed grain only.

A different set of concerns may apply in developing countries, where the priority is food security, especially the availability of sufficient food for the family. The Consultative Group for International Agricultural Research (CGIAR) sees a need to prioritise increase in yield potential and closing the yield gap in high-yielding annual crops, especially under irrigation, to meet projected food demand. They discourage investment in perennial crops, as this may dilute yield gains. Such an analysis only considers grain supply, however, and not ecosystem services, such as minimising soil erosion, maintaining soil fertility, and providing diversified and stabilised systems contributing livestock as well for balanced nutrition.

At issue is a perceived trade-off with perennial crops (Connor *et al.,* 2011), which have to invest in perennial structures, at the expense of potentially directing that investment to further grain yield in the annual crop (see Cattani *et al.* 2014, this volume). Nevertheless, the additional investment in the perennial crop could result in increased acquisition of resources, which could compensate for their redeployment to perennial structures, or even result in yield gains overall (Glover, 2010; Glover *et al.* 2010a,b). There is a dearth of hard data on these issues, however, and it is essential that the perennial crops community address this.

There is also a wider imperative for developing perennial crops, in order not to cater only to those living and farming in productive irrigated areas. The green revolution neglected those remote from favourable ecosystems, and such input-dependent solutions had many pest and ecological concerns. Impact is needed in all farming systems, including the oft-neglected mixed farming systems in the diversified remote uplands of Asia, Africa and Latin America.

WHAT CAN BE DONE TO ADDRESS AND CHANGE THOSE PERCEPTIONS?

We need to show what these materials can do: ground cover, regrowth, floret fertility, forage dry matter (DM), resource capture, soil health, grain yield, disease, quality, biodiversity, ecosystem benefits, runoff, percolation, leaching. To do this well, we need to use a systems approach, and explore where the perennial crops would fit into the current and future farming systems.

Would the perennial displace the annual crop, or more likely, would it be preferentially suited to particular soils or situations, thereby contributing to the diversification and stability of the whole farming system and landscape. What is the plant requirement?? What traits should they possess?? What materials are available, and what are they capable of at this stage of development?? How do we go about improving them?? What are the next steps??

WHERE ARE WE UP TO IN DEVELOPING PERENNIAL CROPS?

As the papers in this volume attest, development of perennial crops ranges from its infancy (e.g. perennial maize and others, Murray and Jessop, 2014; Van Tassel *et al.,* 2014*;* Geleta *et al.,* 2014; Gross and Miller, 2014, this volume), to intermediate (e.g. perennial wheat, Jones *et al.,* 2014, this volume), to approaching reality (e.g. perennial sorghum, Paterson *et al., 2014;* Cox *et al., 2014;* Bozzini, 2014; perennial rice, Sacks *et al., 2014;* Hu *et al.,* 2014*;* Hill, 2014; and perennial legumes, Snapp *et al.,* 2014, this volume). The level of progress has depended in part on the duration of effort, and the complexity of genetic barriers encountered between domesticated and related wild species (Cox *et al.,* 2002). The latter issue has prompted the alternative approach of domesticating the wild species instead (e.g. *Thinopyrum intermedium*, Dehaan *et al.,* 2014, this volume). The diversity of species, approaches, and ecosystems targeted is positive, as we sort out what opportunities may arise. Nevertheless, as researchers and donors consider their strategies for the future, some targeting of investment by farmer demand, ecological need, breeding progress, and policy implication is likely (see below, and also Dixon and Garrity, 2014, this volume).

Further, sustained progress and the development of perennial crops targeted to farmer needs is likely to require systems approaches, in order to assist compatibility with farmer practice and the likelihood of adoption. To explore this, and to set up a basis for examining policy implications, two cases are examined: perennial wheat in Australia as a case study for a developed country, and perennial rice in Asia as a case study for a developing country.

PERENNIAL WHEAT IN AUSTRALIA AS A CASE STUDY FOR A DEVELOPED COUNTRY

An example of the use of the systems approach is provided by research in perennial wheat in Australia, supported by related efforts in the United States of America. Bell *et al.* (2008) used MIDAS, a bioeconomic model of a mixed crop-livestock farming system to explore what role perennial wheat may play in the farming system. Perennial wheat used solely for grain production was not selected as part of an optimal farm plan under the standard assumptions. In contrast, dual-purpose perennial wheat that produces grain and additional forage during summer and autumn could increase farm profitability substantially (AU$20/ha over the whole farm) and 20 percent of farm area was selected for perennial wheat production on the optimal farm plan under the standard assumptions. As little as 800 kg/ha of forage from perennial wheat could reduce demands on stubble over summer and grain supplement at break of season and increase farm stock numbers. The additional value of this timely grazing reduced the relative yield required for perennial wheat to be profitable to just 40 percent of that of the annual wheat crop. This analysis suggested that dual-purpose perennial wheat would be a profitable option for mixed crop/livestock farmers.

The challenges in developing perennial wheat for Australia were reviewed by Bell *et al.* (2010), following ground-breaking work in the United States to generate amphiploids between annual *Triticum* and perennial *Thinopyrum* species (Cox *et al.* 2010; Murphy *et al.* 2010). Experimental efforts in Australia commenced by evaluating a diverse array of putative perennial wheat derivatives including germplasm imported from the United States perennial wheat programs, Russian and Chinese wide-cross germplasm and assorted lines from the Australian Wheat Collection. This initial evaluation of over 150 wheat x wheatgrass derivatives assessed capacity to regrow post-harvest, and yield grain over successive years, thereby identifying characteristics common to surviving breeding lines (Hayes *et al.* 2012; Jaikumar *et al.* 2012). Several entries persisted to produce grain over three successive years. Regrowth was associated with the presence of at least one whole genome equivalent (14 chromosomes) from the perennial donor species. This research established that developing a perennial wheat may be feasible, even though existing germplasm was not intended for Australian conditions, nor was it yet sufficiently developed to be deployed commercially.

The research continues with further field evaluations of perennial wheat derivatives, including previously untested germplasm, and an additional fourth year of those entries surviving from the initial report. In addition, three more-detailed experiments were examined, which used a common set of six genotypes to evaluate forage biomass production under serial defoliation, changes in root-shoot partitioning of DM over successive regrowth cycles, and dehydration tolerance and plant survival under severe water deficit and re-watering. Based on this evidence, a breeding approach for developing adapted perennial wheat for Australian farmers has been proposed (Larkin *et al.* 2014; Larkin and Newell, 2014, this volume).

Further, this research establishes a need to pursue mechanistic understanding in order to make sustained progress. Some of the United States material is reported to be perennial in the glasshouse, but fails to survive in the field. When grown in Australia, however, some of this material has survived and regrown in the field for three seasons. Is this due to the severity of abiotic stresses encountered, such as cold and snow cover in winter, and severe drought and high temperature in summer. Is survival due to better agronomy such as rotation with Brassicas, a different soil or its key attributes such as pH or drainage, or is it related to tolerance to particular diseases such as root and crown rots. By understanding why materials fail in different situations, sustained breeding and agronomic progress is more likely to result.

PERENNIAL RICE IN ASIA AS A CASE STUDY FOR A DEVELOPING COUNTRY

A second case study is drawn from perennial rice in Asia. Perennial rice was originally proposed as a plant type to improve soil stability on sloping uplands, while contributing forage for livestock and grain for the farmer. Initially, crosses were made between *Oryza sativa* and *Oryza longistaminata*, and between *Oryza sativa* and *Oryza rufipogon* (Sacks *et al.* 2014, this volume), which provided sources of nematode and drought resistance from the wild species. The materials were passed to Yunnan Academy of Agricultural Sciences in Kunming China, where Professor Fengyi Hu and his team continued the breeding effort with great success. By selection and repeated backcrossing, they were able to increase spikelet fertility while retaining perennial traits allowing regrowth. Suitable plant types for favourable lowland environments have resulted, with one entry, PR23, now in pre-release testing in Yunnan province. In addition, two QTL for rhizome development have been identified and sequenced (Hu *et al.* 2014, this volume). Breeding and genetic progress in perennial rice has been impressive, but the associated understanding of target environments, and how the materials generated perform in them, is at its early stages, though is now being addressed in field experiments in Yunnan Province in China, and in Savanakhet and Champassak Provinces in neighbouring Lao PDR (Wade and Sengxua, 2014). There is a need to build on this collaboration to further strengthen the characterisation, agronomy, physiology and field testing in association with the breeding program, to ensure sustained progress in the future. In particular, success in addressing the original target, perennial rice for the drought-prone rainfed lowland and upland environments, will require additional investment and collaboration, especially for perennial survival and regrowth in harsh dry conditions.

WHAT ARE THE POLICY IMPLICATIONS FOR THE DEVELOPED COUNTRY?

In the developed country, high priority was allocated to protection of the established annual crop, its production and marketing system. At issue is concern with disease, weediness or poor grain quality. Any proposed breeding effort must ensure levels of disease resistance at least equal to currently released cultivars, for the most common diseases such as stem rust, leaf rust, stripe rust, and septorias. The intent is to ensure the perennial crop could not act as an out-of-season stepping stone to development of spore epidemics, nor to encourage mutation and breakdown of resistance of useful genes. To an extent, the risk here may be less than envisaged, as there is unlikely to be a large green canopy on the perennial crop when soil water is limiting after harvest. The perennial nature, however, may render certain diseases even more important than in the annual crop. Examples include insect-transmitted viruses such as wheat streak mosaic virus and barley yellow dwarf virus. Nevertheless, the wild progenitors possess strong resistance to these viruses, which the evidence suggests is passed to the progeny. For Australia, the root and crown rots may be a special threat for perennials, with the intention to grow the perennial crop for several seasons. Here, crop rotation with brassicas and soil health will be important to ensure levels of infection are initially low, as resistance is not strong against many root and crown rots. Nevertheless, it will be important to include the best resistance available for these critical diseases. To address these concerns, the developed country may require specified levels of resistance to particular diseases, or require the perennial only be grown for a specified number of seasons before rotating to another crop.

The perennial parent of many of the perennial wheats, *Thinopyrum intermedium*, is a prohibited species in Australia, requiring stringent quarantine procedures before the perennial wheats could be grown in the field in Australia. The concern was robust or long rhizomes, which may be hard to kill, and which could pose a significant weediness threat. Fortunately, the introduced lines did not possess rhizomes, and their regrowth was in the form of tillers in the next cycle from the crown of the plant. Hence the risk of weediness was greatly reduced, but it is still worthwhile checking progeny to make sure. To address this, the developed country may require that released perennial wheats only regrow as tillers not rhizomes.

Grain quality is a critical element of successful marketing of Australian wheat to meet quality requirements for a number of carefully defined markets. Grain is delivered to separate silos, and handled and marketed separately, to ensure consistent quality. Were a lower grain quality perennial wheat to be released, its grain would need to be segregated, perhaps as feed wheat only. Such arrangements are already in place, so should be acceptable, though no doubt there would be concern if larger quantities of low quality wheat were delivered, relative to the more desirable high-quality, higher-priced grain. To address this concern, grain must be segregated by quality and sufficient facilities must be available to cope, until grains of comparable quality become available. The importance of grain quality, and the associated benefits to human health, is considered in several papers in this proceeding (Pogna *et al.* 2014; Sands *et al.* 2014, this volume).

WHAT ARE THE POLICY IMPLICATIONS FOR THE DEVELOPING COUNTRY?

To an extent, the issues for the developing country may include aspects of those for the developed country above, but the contrast may relate to grain for export versus feed for the family. In the developing country, food security and livelihood for the farmer and the family are paramount, especially assurance of food supplies until the next harvest. Governments in developing countries may be more willing to explore opportunities, to see what benefits could accrue for subsistence farmers, and those governments are very concerned with sustained production. Hence, developing countries may more readily recognize the potential opportunities with perennial crops and allow farmers to explore them.

WHERE WILL PERENNIAL CROPS BE GROWN AND WHAT WILL BE THE CONSEQUENCES?

The discussion above is designed to draw attention to the reality that perennial crops are unlikely to soon replace high-yielding annual crops as the mainstay of grain production. More likely, they will fulfil niche roles across the landscape, perhaps being selected to stabilise land intermediate between prime cropping and grazing only, especially if some soil remediation is needed. As such, a perennial crop is most likely to be dual purpose, including provision of timely feed to livestock. The analyses of Bell *et al.* (2008) and Pimentel *et al.* (2012) provide examples of the potential roles of perennial wheat. Likewise, mountain uplands may provide a scenario ideal for inclusion of perennial rice. The lowland paddy at altitude would still support high-yielding annual rice and other crops, but the surrounding sloping uplands, where upland rice is normally grown, may be ideal for perennial rice for grain and grazing, perhaps in conjunction with either agroforestry or self-regenerating annual legumes for further diversification and system stability. Another example is intercropping of annual peanut and perennial pigeon pea in Malawi (Snapp *et al.* 2014 this volume), to provide not only feed for farmer and livestock, but also nitrogen to a following maize crop. In each of these examples, the landscape is improved, with a more productive and stable multi-purpose farming system.

WHAT WE NEED TO DO NEXT

The most critical issue facing the perennial crops community is to build credibility and confidence in the broader scientific population, and especially in the donor community. To do this, we need to collect and publish hard data on the performance of perennial crops, and especially on tradeoffs in performance, benefits to resource capture and timeliness, and alternative systems benefits such as via livestock or ecosystem services. Previously, publications from the perennial crops community tended to be longer on exciting concepts, but shorter on evidence to demonstrate what they could actually deliver. Some publication streams are now in progress to address this, but further effort is needed. I believe donor success is related not only to concept development in exciting proposals, but also to hard evidence and strong track records of delivery. Given these are questions about the validity of developing perennial grains, e.g. yield tradeoffs, grain security, we must assemble and publish evidence to demonstrate the viability of our visions, and also, a likely time frame to their achievement. This workshop is an ideal foundation for a coordinated effort to develop perennial crops, based on sound scientific evidence, relevance to farmer needs, and in a manner compatible with sustainable and profitable farming systems (see also Snapp *et al.* 2014 and final chapter, this volume).

CONCLUSIONS

Prospects for developing perennial crops are bright, especially if efforts are targeted to appropriate environmental niches with appropriate species. For example, the Grains Research and Development Corporation has recently listed perennial wheat as a technology on the horizon, which has potential to contribute to the next substantial advance in Australia. Perennial rice line PR23 is now in pre-release testing in the Yunnan Province of China, raising prospects of commercial release to farmers shortly. Annual peanut-perennial pigeon pea-maize is already being used by farmers in Malawi. Hence, opportunities to include perennial crops in productive, stable and sustainable dual-purpose systems are appearing already. We need to continue our efforts and document our progress as we proceed in order to ensure support of scientific and donor communities towards a perennial cropping systems future.

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