19
PERENNIAL GRAIN SYSTEMS: A SUSTAINABLE RESPONSE TO FUTURE FOOD SECURITY CHALLENGES

John P. Reganold
Department of Crop and Soil Sciences, Washington State University
Pullman, WA 99164-6420, USA

ABSTRACT

Although conventional agricultural systems have provided growing supplies of food and other products, they have also been major contributors to global greenhouse gases, biodiversity loss, natural resource degradation, and public health problems. Concerns about the long-term sustainability of agriculture, especially in light of a growing population, have promoted interest in new transformative approaches to agriculture. Transformative approaches meet FAO's multiple goals of sustainable intensification: increasing crop production per unit area and enhancing environmental, economic, and social sustainability. Perennial grain systems are examples of such innovative systems but perennial grains, such as wheat and maize, will not be commercially operational for at least 15 to 20 years. For any perennial grain to be commercially available by 2030, more resources are needed to (i) accelerate plant breeding programmes with more personnel, land, and technological capacity; (ii) expand agro-ecological research on improved perennial germplasm; (iii) coordinate global activities through germplasm and scientist exchanges and conferences; (iv) identify global priority croplands; and (v) develop training programmes for scientists and students in the breeding, ecology, and management of perennial crops. In addition, farmer involvement, public-private collaborations, and significant changes in markets and policies will be necessary. Large investments have been committed to developing technologies for biofuel conversion of perennial crops because of their ecological advantages compared to annual sources, despite their potential to displace food crops. With similar commitments for developing food-producing perennial grains, commercially viable perennial grain crops could be available by 2030.

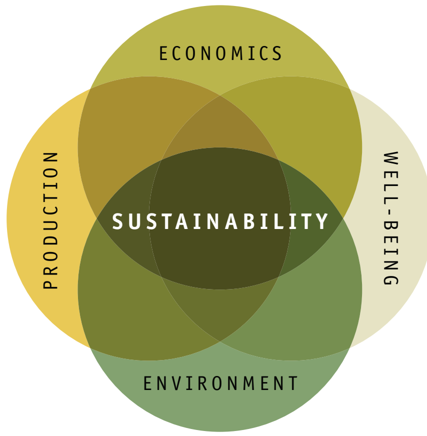
Keywords: agricultural research investment, ecosystem services, perennial grains, sustainability indicators, sustainable agriculture, transformative farming systems

THE MULTIPLE GOALS OF SUSTAINABLE AGRICULTURE

With increasing population pressure and finite resources, is it possible to meet both global food security needs and sustainability needs? According to Foley *et al*. (2011), tremendous progress could be made by (i) halting agricultural expansion, (ii) closing "yield gaps" on underperforming lands, (iii) increasing agricultural resource efficiency, (iv) shifting diets, and (v) reducing waste. Together these strategies could double food production while greatly reducing the environmental impacts of agriculture. Perennial grains could directly address (ii) and (iii).

To do so requires transformative farming systems to address global food security challenges. Why transformative? Because so many serious problems in agriculture exist as a result of not addressing multiple sustainability goals. According to a National Research Council report (2010) from the U.S. National Academy of Sciences, the multiple goals of sustainable agriculture are to (1) provide abundant, affordable food, feed, fibre and fuel; (ii) enhance the natural-resource base and environment; (iii) make farming financially viable, and (iv) contribute to the well-being of farmers, farm workers and farm communities. The National Research Council definition has similarities to that of FAO's "sustainable intensification", which is defined as increasing crop production per unit area and improving environmental, economic and social sustainability via management of biodiversity and ecosystem services (FAO, 2008). Sustainability is thus the intersection among economics, well-being, production, and environment (Figure 1).

FIGURE 1. THE FOUR COMPONENTS OF AGRICULTURAL SUSTAINABILITY



INCREMENTAL AND TRANSFORMATIVE APPROACHES TO SUSTAINABLE AGRICULTURE

The National Research Council report (2010) criticised mainstream, conventional farming for not addressing multiple sustainability goals. It identified numerous examples of innovative farming systems and practices that contribute to multiple sustainability goals, but noted they are not widespread. In order to improve the sustainability of U.S. agriculture, the National Research Council Report proposed both incremental and transformative approaches.

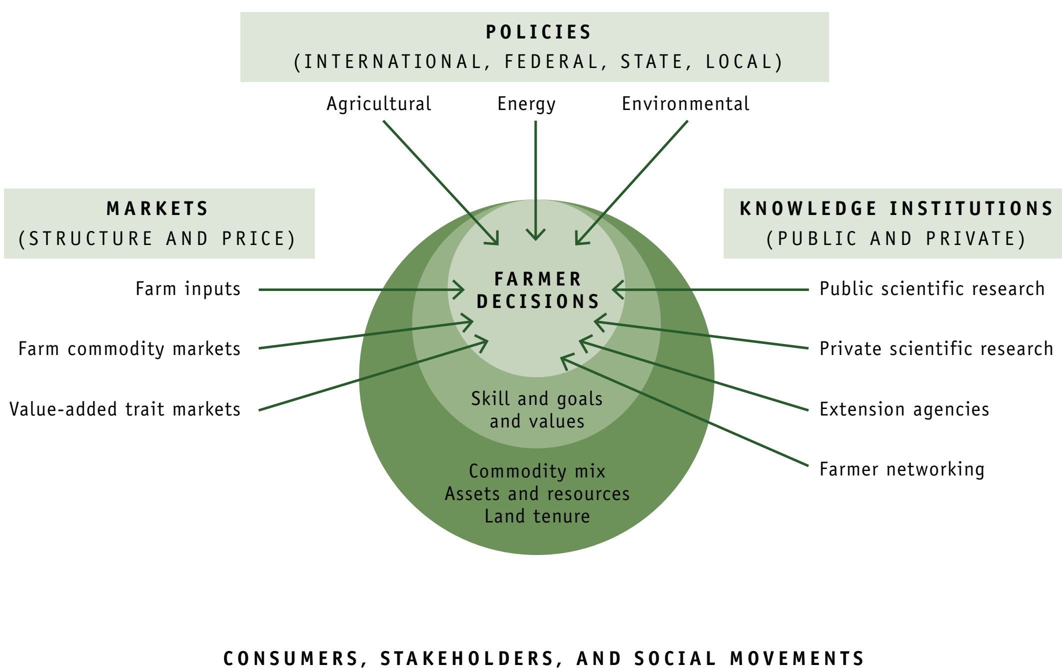
Incremental approaches are practices and technologies that address specific production or environmental concerns associated with mainstream conventional farming systems. Examples include two-year rotations, precision agriculture, classically bred or genetically engineered crops, and reduced or zero tillage. Incremental approaches offer improvements and should continue, but individually, are inadequate to address multiple sustainability concerns.

Conversely, transformative agricultural systems integrate production, environmental, and socioeconomic objectives and reflect greater awareness of ecosystem services on large, mid-size, and small farms. Examples include conservation agriculture, organic farming, mixed crop/livestock farming, integrated (hybrid) systems, agroforestry, and perennial grains.

COEXISTENCE OF DIFFERENT FARMING SYSTEMS

The future requires a coexistence of different farming systems that are sustainable. No one farming system will safely feed the planet, but rather a blend of farming systems will be needed. Proper alignment and coexistence of different farming systems at the landscape level will likely play a key role in future food and ecosystem security. The existence of innovative agricultural systems suggests that technical obstacles are not the greatest barrier. Rather, change is hindered by market structures, policy incentives, and uneven development and availability of scientific information that guide farmers' decisions (Reganold *et al*. 2011) (Figure 2).

FIGURE 2. DRIVERS AND CONSTRAINTS AFFECTING FARMERS' DECISIONS



An illustration of farmers embracing this decision-making process and striving for sustainability is Shepherd's Grain, a marketing label and alliance of a group of farmers in the U.S. Pacific Northwest, who use sustainable production practices and market differentiated wheat products together. Shepherd's Grain was founded by Karl Kupers and Fred Fleming, two U.S. direct-seed farmers from the large commercial grain-producing Palouse region in the states of Washington and Idaho. It has drawn growing attention from agrifood researchers and activists as an example of new "value chains" that can help support an "agriculture of the middle." Shepherds' Grain growers tend the soil and harvest wholesome wheat from farms across the Palouse but have to meet certain sustainability criteria, as defined and certified by the Food Alliance in Portland, Oregon. Shepherd's Grain wheat flours are sold in local health food stores throughout the U.S. Pacific Northwest and northern California and purchased by consumers for their quality, localness, and sustainability certification brand.

THE NEED FOR FARMING SYSTEMS RESEARCH

Unfortunately, most federal research grant programmes in the U.S. and globally still primarily support incremental research. For example, the bulk of public and private agricultural science in the U.S. is narrowly focussed on productivity and efficiency, particularly on technologies that fit into existing production systems and lead to private benefits (Reganold *et al*. 2011). We need to reallocate public funds to support transformative farming systems and systems research that measures multiple sustainability indicators at field, farm, and landscape scales.

Specifically concerning perennial grain systems, we need more studies as only relatively few have been conducted on perennial grains (e.g. Bell *et al*. 2008; Snapp *et al*. 2010; Hayes *et al*. 2012; Jaikumar *et al*. 2012). Moreover, we need farming system comparison studies, with replicates on a commercial farm or experiment station, or with commercial farms as replicates, in which early varieties of perennial grains are grown by themselves, in polycultures with other perennial grains, or in rotation with annual grains.

Such farming system studies require metrics for evaluating and measuring quantifiable components of a farming system. Since we would like a farming system to achieve multiple sustainability or ecosystem service goals, we can measure sustainability indicators or ecosystem services. Measuring a suite of sustainability indicators yields valuable results of a farming system's performance and health. Examples of indicators that can be used for measuring a farm's sustainability are listed in Figure 3. Of the four legs of sustainability – economics, well-being (social), production, and environment – the social sustainability indicators have been the least evaluated in comparison studies (Reganold, 2013).

FIGURE 3. EXAMPLES OF SUSTAINABILITY INDICATORS

SUSTAINABILITY INDICATORS

CROP/ANIMAL YIELD AND QUALITY
yield; plant nutrients; protein content; storage potential; vitamins; weed populations; insect pressure; disease

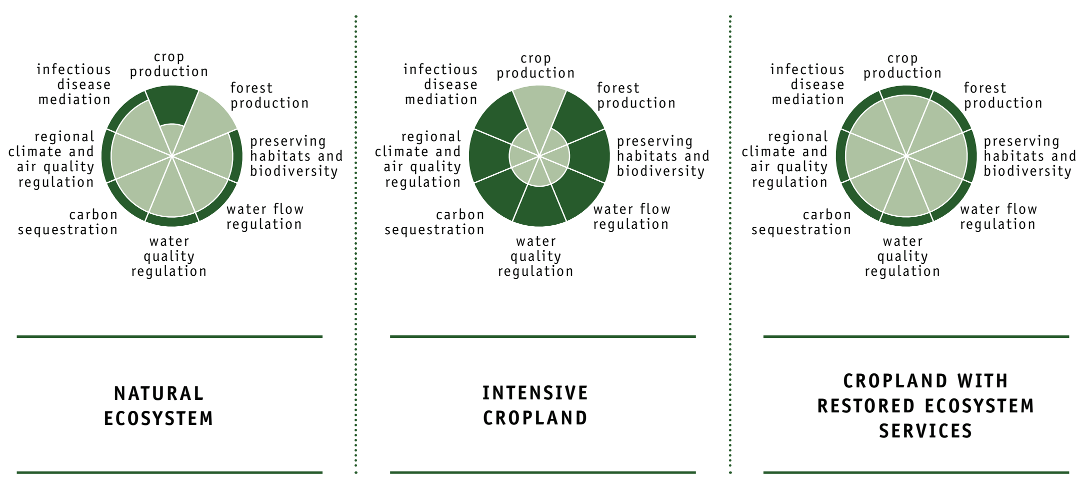
FINANCIAL PERFORMANCE
benefit/cost ratios; net returns; breakeven points; externalities

ENVIRONMENTAL QUALITY
soil health; pesticide and fertilizer impacts; soil erosion; surface and ground water pollution; energy efficiency

SOCIAL JUSTICE
worker wages, benefits, and safety; community well-being

In ecosystem studies, scientists have used ecosystem services as metrics. Examples of ecosystems services that can be measured on farms or plots are crop production, preserving habitats and biodiversity, water flow regulation, water quality regulation, carbon sequestration, air quality regulation, and infectious disease mediation. Figure 4 provides a good example by Foley *et al*. (2005), who illustrate ecosystem services under three contrasting land-use regimes: natural ecosystem, intensive cropland, and cropland with restored ecosystem services (Fig. 4).

FIGURE 4. COMPARING ECOSYSTEM SERVICES UNDER THREE LAND-USE REGIMES



Source: Reganold *et al.*, 2011

One could also measure a combination of sustainability indicators and ecosystem services. A good example of this is research by Glover *et al*. (2010), who evaluated sustainability indicators and ecosystem services between conventionally farmed grain fields and organically managed perennial grasslands at a range of spatial and temporal scales. First, they used commercial paired farm fields as replicates to evaluate ecosystem components of conventionally farmed grain fields and adjacent organically managed perennial grasslands. To make more refined determinations at smaller scales, they initiated replicated treatments on one of the farms. They also used watershed replicates in which the commercial farm replicates were embedded to make other larger-scale determinations.

THE CASE FOR PERENNIAL GRAINS

Farmers in this relatively young millennium face compounding pressures to meet the food needs of a growing, more demanding human population while reducing and reversing the extensive land degradation related to agriculture. Humans have more than doubled the yields of major grain crops over the past 60 years, and yet roughly one in seven people suffer from malnutrition (FAO, 2009). As the global population continues to grow, the demand for food, especially meat, also increases. Additionally, production of nonfood goods (e.g. biofuels) increasingly competes with food production for land and much of the land most suitable for annual crops is already in use (Godfray *et al*. 2010). Global food security largely depends on these annual grains—cereals, oilseeds, and legumes—that are planted on almost 70 percent of croplands and supply a similar portion of human calories. Three annual crops alone—maize, rice, and wheat—provide over 60 percent of human calories. Their production, though, often compromises essential ecosystem services, pushing some beyond sustainable boundaries (Cassman and Wood, 2005; Glover *et al*. 2010).

Current annual cereal crop production on large areas of marginal lands, particularly those on steeply sloping croplands, results in further land degradation and is unlikely to be sustainable over the long term (Cassman *et al*. 2003). These areas are much more suitable for perennial crops, such as forages and biofuels. Unfortunately, food security concerns and/or the greater market value of staple grains often pressure farmers to choose to plant annual grain crops instead of perennial crops even on lands poorly suited to their production. For these farmers, there are too few options to simultaneously meet their food, income, and ecosystems security needs. Meanwhile, the health of their farms continues to deteriorate at the very time that increased grain yields are critical. Facing the triple threats of climate change, land degradation, and a growing human population, business-as-usual approaches to transforming agriculture are no longer acceptable.

Perennial versions of the major grain crops, cereals, grain legumes, and oilseeds, would offer farmers more opportunities to meet their food and income needs while protecting their natural resources even on lands poorly suited to annual crop production. This is not an entirely new idea. Pioneering Russian scientists in the 1930s started perennial wheat breeding programmes and were followed by efforts in the United States in the 1960s (Cox *et al*. 2006). The technologies and resources of the time though limited the success of these programmes. The perennial wheat breeding efforts, for example, were abandoned in part because of plant sterility and undesirable agronomic characteristics (Cox *et al*. 2006). More recently, programmes have been initiated in Argentina, Australia, China, India, Nepal, Sweden, and the United States to identify and improve, for use as grain crops, perennial species and hybrid plant populations derived from annual and perennial parents: rice, wheat, maize, sorghum, pigeon peas, and oilseed crops from the sunflower, flax, and mustard families (Glover *et al*. 2010).

While perennial plant breeding programmes may not produce wide-scale impacts in farmers' fields for another 15 to 20 years, there is emerging evidence that novel perennial grain-based systems provide unique opportunities for protecting water and soil resources, while addressing the pressing problem of climatic variability. Even on the best croplands, perennial crops typically sequester more carbon, better protect soil and water resources, are more resilient to climatic changes, and are more productive above- and below-ground (Cox *et al*. 2006). Compared to annual crops, perennials have the potential to double sequestered carbon, and some can fix nitrogen. The extensive root systems and vegetative cover of perennial crops are the biological foundation to a 'climate smart' agriculture that captures and utilizes water resources, rehabilitates soil, and sequesters carbon. At the same time, food production must be a priority in the design of farming systems. This ensures immediate returns in the form of food security and economic benefits, in addition to environmental services from well-designed combinations of perennial, semi-perennial, and annual crops. Development of perennial grain crops has been termed the missing ingredient, as staple crops have historically been dominated by annual life forms (van Tassel *et al*. 2010).

RECOMMENDATIONS AND CONCLUSIONS

Large investments have been committed to developing technologies for biofuel conversion of perennial crops, despite their potential to displace food crops. With similar commitments for developing food-producing perennial grains, commercially viable perennial grain crops could be available by 2030. Public policies (e.g. the United States Farm Bill) and private funding are needed to support perennial grain systems. However, different strategies will be necessary to get funding for perennial grain development in specific countries, especially in developing compared to developed countries.

For any perennial grain to be commercially available by 2030, more resources are needed to do the following:

1. Accelerate plant breeding programmes with more personnel, land, and technological capacity;
2. Expand agro-ecological research on improved perennial germplasm; for example, we need perennial grain farming systems research on large plots and commercial-sized farm fields,

which in turn can generate confidence in further research investment. Such systems studies can be comparison studies with annual grain or mixed perennial/annual grain systems;

3. Support farmer involvement and develop public-private collaborations;
4. Coordinate global activities through germplasm and scientist exchanges and conferences;
5. Develop training programmes for scientists and students in the breeding, ecology, and management of perennial crops; and
6. Establish a World Perennial Grain Research Centre where resources can be focussed, priorities identified, and information and germplasm exchanged.

We need to change the discussion from annual versus perennial to complementary blends of the two. In addition, we need to better sell perennial grain systems based on their multiple sustainability benefits for global food security. Along these lines, including externalities and ecosystem services in economic studies would illustrate the financial viability of perennial grain systems. Perennial grains need to be more demand-driven by national governments, research institutes, and farmers and less supply-driven by institutions in developed countries. We need a systematic analysis of the highest potential perennial grain crops in development and the potential regions and global priority croplands where they are needed the most or can grow best.

Finally, we need to better communicate about perennial grains. If we want to reach farmers, producers, consumers, and extension agencies, social media utilities, such as YouTube videos, blogs, Facebook, and webpages, need to be used. Outreach events, such as field days and presentations, are also important. Perennial grain research findings from journals need to be reported in extension and outreach bulletins, articles in popular trade journals, and government technical guides and fact sheets.

REFERENCES

Bell, L.W., Byrne, F., Ewing, M.A. & Wade, L.J. 2008. A preliminary whole-farm economic analysis of perennial wheat in an Australian dryland farming system. *Agricultural Systems*. 96: 166–174.

Cassman, K.G., Dobermann, A., Walters, D.T. & Yang, H. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. *Annual Review of Environment and Resources*. 28: 315-358.

Cassman, K.G. & Wood, S. 2005. Cultivated Systems. In: Hassan, R., Scholes, R. & Ash, N. (eds.) *Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Current State and Trends*, Volume 1. Island Press, Washington D.C. pp. 745-794.

Cox, T.S., Glover, J.D., Van Tassel, D.L., Cox, C.M. & DeHaan, L.R. 2006. Prospects for developing perennial grain crops. *BioScience*. 56: 649-659.

FAO. 2008. *Investing in Sustainable Agricultural Intensification. The Role of Conservation Agriculture. A Framework for Action*. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO. 2009. *The State of Food Insecurity in the World 2009. Economic Crises—Impacts and Lessons Learned*. FAO, Rome. (Available at ftp://ftp.fao.org/docrep/fao../012/i0876e/i0876e.pdf).

Foley, J.A. Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., & Siebert, S., Tilman, D. & Zaks, D.P.M. 2011. Solutions for a cultivated planet. *Nature*. 478: 337–342.

Glover, J.D., Culman, S.W., DuPont, S.T., Broussard, W., Young, L., Mangan, M.E., Mai, J. G., Crews, T.E., DeHaan, L.R., Buckley, D.H., Ferris, H., Turner, R.E., Reynolds, H.L. & Wyse, D.L. 2010. Harvested perennial grasslands provide ecological benchmarks for agricultural sustainability. *Agriculture, Ecosystem and Environment*. 137: 3-12.

Glover, J.D., Reganold, J.P., Bell, L.W., Borevitz, J., Brummer, E.C., Buckler, E.S., Cox, C.M., Cox, T.S., Crews, T.E., Culman, S.W., DeHaan, L.R., Eriksson, D., Gill, B.S., Holland, J., Hu, F., Hulke, B.S., Ibrahim, A.M.H., Jackson, W., Jones, S.S., Murray, S.C., Paterson, A.H., Ploschuk, E., Sacks, E.J., Snapp, S., Tao, D., Van Tassel, D.L., Wade, L.J., Wyse, D.L. & Xu, Y. 2010. Increased food and ecosystem security via perennial grains. *Science*. 328: 1638-1639.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. 2010. Food security: The challenge of feeding 9 billion people. *Science*. 327: 812-818.

Hayes, R.C., Newell, M.T., DeHaan, L.R., Murphy, K.M., Crane, S., Norton, M.R., Wade, L.J., Newberry, M., Fahim, M., Jones, S.S., Cox, T.S. & Larkin, P.J. 2012. Perennial cereal crops: An initial assessment of wheat derivatives. *Field Crops Research*. 133: 68–89.

Jaikumar, N.S., Snapp, S.S., Murphy, K. & Jones, S.S. 2012. Agronomic assessment of perennial wheat and perennial rye as cereal crops. *Agronomy Journal*. 104: 1716-26.

National Research Council. 2010. *Toward Sustainable Agricultural Systems in the 21st Century*. The National Academies Press, Washington, D.C.

Reganold, J.P. 2013. Comparing organic and conventional farming systems: metrics and research approaches. *Crop Management*. doi:10.1094/CM-2013-0429-01-RS.

Reganold, J.P., Jackson-Smith, D., Batie, S.S., Harwood, R.R., Kornegay, J.L., Bucks, D., Flora, C.B., Hanson, J.C., Jury, W.A., Meyer, D., Schumacher, Jr., A. Sehmsdorf, H., Shennan, C., Thrupp, L.A. & Willis, P. 2011. Transforming U.S. agriculture. *Science*. 332: 670-671.

Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner-Kerr, R. & Kanyama-Phiri, G.Y. 2010. Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences USA*. 107: 20840-20845.

Van Tassel, D.L., DeHaan, L.R. & Cox, T.S. 2010. Missing domesticated plant forms: can artificial selection fill the gap? *Evolutionary Applications*. 3: 434-452.