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Perennial Crops Are a Key to Sustainably Productive Agriculture**

Lee R. DeHaan, Ph.D.
Plant Geneticist, The Land Institute, Salina, Kansas, U.S.

Summary

Agricultural production of grain is central to the global food supply, and grain fields dominate vast regions of the landscape. Despite improvements, grain production still results in soil erosion and loss of nutrients into ground and surface water where they become pollutants. Replacing annual grain crops with perennial plants (which live for several years without replanting) has potential to remedy most of the limitations to sustainability seen in grain cropping systems, while expanding productivity. Currently, policy supports the development of perennial crops, such as switchgrass, that would be dedicated to biofuel production. Such perennial biofuels could protect soil and water, but may have unintended consequences as they compete for land on which to grow food. A better solution is to develop perennial crops that produce food for human consumption, with residues available for biofuel. To enable widespread success of perennial crops and insure their sustainability benefits, agricultural policy should begin by moving away from support of particular commodities (e.g., corn, soybeans, wheat) and instead pay producers for providing ecosystem services, including clean water, carbon sequestration, and wildlife habitat. Government mandates for biofuels should be phased out. Instead, resources should be dedicated to sustained efforts to develop new perennial crops that can primarily produce human-edible food, and secondarily provide residue that is usable as biofuel or livestock feed.

Current realities

More than 75% of human food calories come from grains, and increases in grain production have enabled a population explosion over the past century. However, the grain systems that now dominate vast regions of the globe generate serious sustainability concerns both on and off the farm. Soil erosion is moderate to severe on 80% of the world's agricultural lands, causing an estimated 10 million hectares to be abandoned every year. As soil quality declines, wild lands are brought into cultivation to maintain an adequate food supply. Fertilizers such as nitrogen and phosphorus run off agricultural lands into ground or surface waters where they become contaminants. Lost fertilizers have an economic cost to farmers, and once in waters they damage wildlife populations and can render water unfit for drinking without expensive treatment. Due to rising population and increasing affluence, global demand for grain in 2050 is expected to be more than double that of 2005. To meet this demand without increased environmental costs, ecological intensification has been proposed. In ecological intensification, ecological principles are invoked to enable greater productivity while protecting soil and preventing off-site impacts. Perennial crops that live for several years will be central to achieving ecological intensification worldwide, since they use more of available sunlight and water to produce greater potential yield, while simultaneously building and protecting soil.

Biofuels have been developed to improve sustainability of energy production, but all of the current technologies and approaches have associated sustainability concerns. Current projects to develop agricultural biofuels fall into three main categories. 1. Grain from annual crops can be made into liquid biofuels. This system has been supported by policy, which has resulted in production of biofuels with poor energy return, no benefit to climate change mitigation, increased soil degradation, higher food cost as food is turned to fuel, and expanded use of nonrenewable resources, such as water stored in nonrecharging aquifers. 2. Crop residues left after harvesting grain could be used as fuels. Residue systems have sustainability concerns similar to or worse than conventional annual grain systems. Residue fuels avoid using human-edible food as fuel, but if a substantial portion of the residue is removed, severe soil degradation can occur. 3. Dedicated perennial biofuels such as grasses or trees could improve soil quality, sequester carbon, and provide ecosystem services such as clean water and wildlife habitat. However, dedicating land to perennial biofuels will compete for land to grow food. As additional lands are tilled for food crops, the result is predicted to be a counterintuitive increase in greenhouse gas emissions.

Crop breeding, historically a mostly public enterprise, is a mature methodology that has primarily moved into the private sector. For existing grain crops, private-sector breeding has provided consistently improved varieties for agriculture in industrialized countries. However, private plant breeding companies are unable to tackle long-term, higher-risk projects of developing completely new crops. Some governments, both state and federal, as well as foundations, are beginning to realize the potential in funding plant breeding to develop new crops with the ability to enhance sustainability for farmers, communities, and ecosystems. Among these new crops are nut trees and shrubs (e.g., hazelnuts), winter-annual grain crops to plant when soil is normally bare (e.g., pennycress), and new perennial grain crops that would yield grain while covering the land year-around (e.g., perennial wheat).

Scientific opportunities and challenges

Recent advances in genetics and plant breeding have made possible the development of new crops, largely herbaceous perennials (e.g., perennial rice, perennial wheat, perennial sorghum), which are capable of providing direct food for humans in the form of grain. These new crops, the first of which is just entering commercial production, are expected to enhance ecosystem services such as carbon sequestration, clean water, soil quality improvement, and wildlife habitat. By using resources more fully and providing a source of sustainable biofuel by-products, these systems are projected to increase productivity of agroecosystems. Although dedicated biofuel crops may compete with food crops for arable land, the residue from perennial grains would be harvestable for sustainable co-production of food and fuel. Furthermore, the aboveground growth can be annually removed from many perennial crops without risking erosion.

One approach used to develop perennial grain crops is *de novo* domestication. Using modern breeding and genetic techniques, we now anticipate the transformation of crops from wild species to useful crops in decades, rather than the centuries it previously took. Domestication projects face the challenges of wild traits such as seed shedding, seed toxicity, small seed size, dormant seed, and difficulty in threshing. These are traits that were overcome in ancient domestication. Now, we can use comparative genomic techniques to assist in the domestication of perennial species that are related, even distantly, to our current annual crops. For instance, new techniques such as TILLING (i.e., induced mutations followed by genomic testing for desired genetic changes) and genome editing can be used to identify or create the gene forms required to accomplish domestication.

Wide hybridization is another major approach that can be used to create perennial grains. In this case, current grain crops are crossed to their wild relatives that are perennials, with the goal of combining perenniality with the domesticated growth form of the crop. In wide hybridization, overcoming sterility can be a major challenge. Combining the desirable traits from the crop and the perennial parent while eliminating the undesirable traits can also be difficult. Basic research is now studying the genetics of perenniality, which is expected to have substantial benefit to perennial grain breeding.

Sustaining seed yield of herbaceous perennials for several years is a challenge for perennial grain production. Although perennials that require rotating to a new crop every three to five years can still have substantial sustainability benefits, extending the productive lifespan of perennials can provide economic benefits and enhanced sustainability. In the short term, low-input management techniques to sustain yield are needed. Planting density, grazing, biomass removal, nutrient management, intercropping, and thinning techniques are being studied to determine their potential to sustain yield. In the longer term, plant breeding should be effective in developing crop varieties with sustained yield that do not require special management.

Policy issues

- Agricultural policy must move away from support for particular commodities (e.g. corn, soybeans, wheat), and toward payment for ecosystem services from working agricultural lands. The strong correlation between perennial cover and reduced nutrient runoff or leaching, improved wildlife habitat, and reduced erosion could be used to structure support for agricultural lands providing increased ecosystem services.

- Government mandates and research support for biofuel crops must move toward perennial species capable of producing human food plus biofuel residues. New and current biofuels should be evaluated on their potential to produce a positive energy balance without depleting natural resources, increasing net greenhouse gas emissions, or reducing global production of human-edible food.

- Funders of agricultural research at all levels (international, federal, and state) need to commit to the development of new crops that can provide enhanced ecosystem services and sustainable yields of human-edible foods. These new crops may come in the form of short-season grains that can be grown when land is usually left bare or perennial grains and woody crops that live for several years or more. Breeding and agroecology programs to develop these new crops will require sustained funding for more than a decade.

- In Florida, agricultural policy needs to support the expansion of rotations that include perennials, such as the sod-based crop rotations that David Wright at the University of Florida has found to be more profitable than continuous annual crop rotations. Subsidies could be redirected from specific cash crops toward payments for sustainable practices, loans or grants to support the purchase of grazing livestock infrastructure, and support for demonstration projects that will help producers to learn about perennial rotations.

References

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