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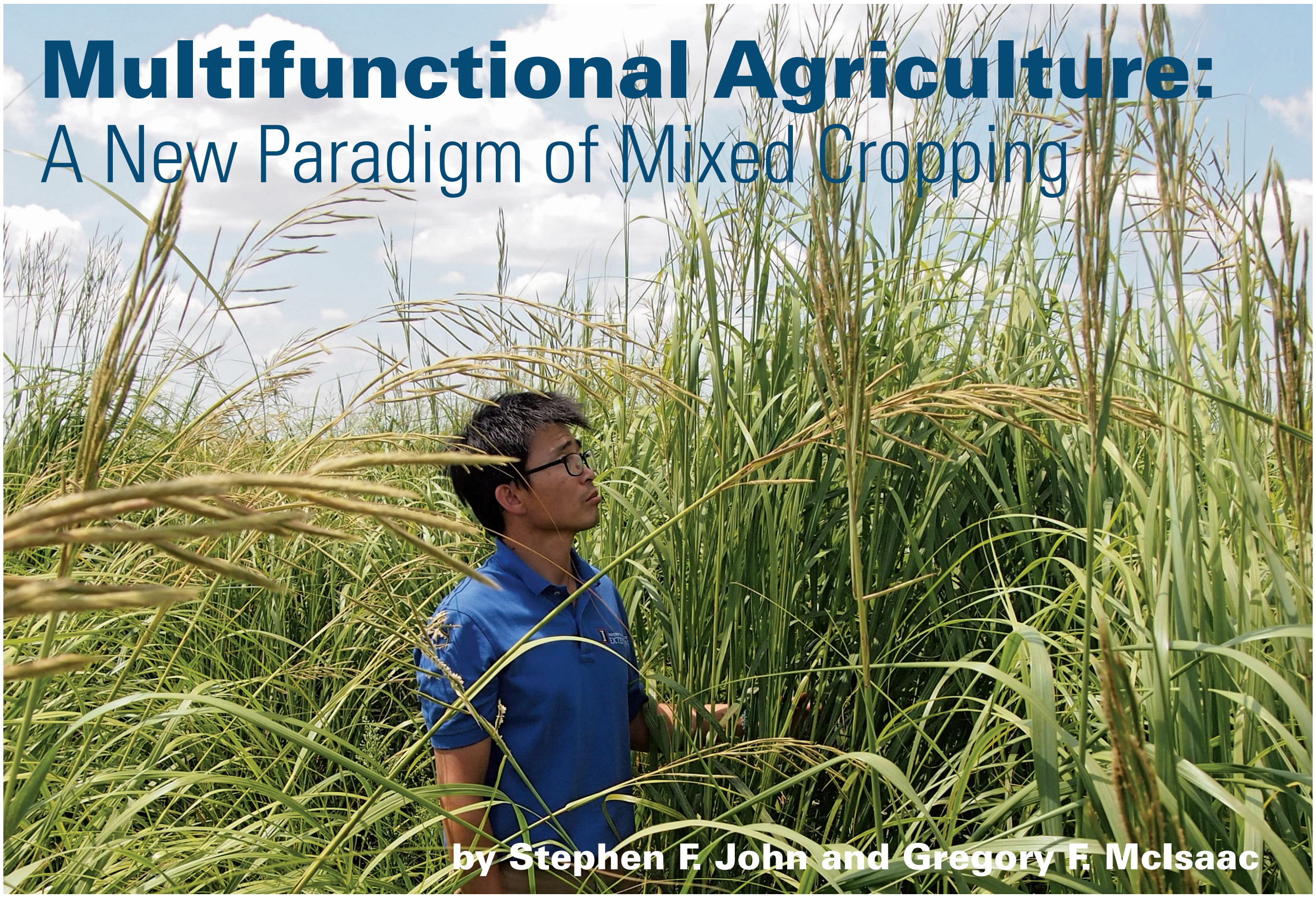
Multifunctional Agriculture:
A New Paradigm of Mixed Cropping



by Stephen F. John and Gregory F. McIsaac

DoKyoung Lee

University of Illinois Associate Professor DoKyoung Lee has developed a cultivar of Prairie cordgrass (*Spartina pectinata*) as a bioenergy crop. Its tolerance of seasonally wet conditions makes it a promising grass for planting in saturated buffers or poorly drained soils to reduce nutrient loss from adjacent row crops.

In Brief

The dominant agricultural paradigm in prime cropland areas of the American Midwest are farms producing corn and soybeans. Within this region, some states in the Mississippi River Basin have developed nutrient loss reduction strategies aimed at decreasing nutrient loading in rivers that contributes to the hypoxic "dead zone" in the Gulf of Mexico. While several conventional conservation practices applied to corn-soybean fields can reduce nutrient loss, converting annual crop acreage to perennial biomass crops would be far more effective.

New and expanded uses and markets for perennial biomass crops are needed in order for them to gain wide adoption. Bioenergy grasses can be used for various bio-based products and for renewable energy in the form of heat, electricity, or transportation fuels. Many of the high-yielding grasses that will be used for bioenergy in the future make good forage for livestock.

U.S. energy policy encouraging cellulosic biofuel production could drive the adoption of perennial biomass crops. Biomass crops are unique among the sources of renewable energy, in that they can also provide a suite of ecological benefits such as clean water, soil health, greenhouse gas reduction, and wildlife habitat. Policy mechanisms to incentivize farmers for these benefits may be necessary for the economic viability of perennial biomass crops in prime crop areas.

Over the next 20 years, multifunctional agriculture featuring perennial biomass crops can become a new paradigm to produce the agricultural goods that society needs, plus important ecosystem services. For that to happen, engagement of a wide range of stakeholders is needed, including farmers, landowners, scientists, conservation professionals, policy makers, entrepreneurs, industrialists, investors, and philanthropists.

Agriculture in much of the Midwestern United States is dominated by farms that produce two annual row crops—corn and soybeans—and have no livestock. Such grain-only farming operations became the norm roughly between 1950 and 1970. They produce a bountiful harvest for many food and non-food uses, but are heavily reliant on fossil fuels. And, even when conscientious farmers follow management practices recommended by Land Grant universities and conservation agencies, farmland dominated by annual row crops contributes to a number of environmental problems including greenhouse gas emissions, loss of wildlife habitat, and hypoxia in the Gulf of Mexico.

As farmers, scientists, and policy makers seek to remedy adverse impacts associated with annual row crops, it is time to change how we think about farms at a field and watershed scale. The shift from fossil fuels to renewables, and the urgency of mitigating and adapting to climate change can be the main drivers of a landscape transformation.

Bioenergy is controversial because it is seen as competing for land with food production and long-term carbon storage in trees and soils.[1] Current federal energy policy calls for ramping up production and transitioning from first-generation biofuels, made from corn and soybeans, to advanced biofuels, made mainly from cellulosic plant material.[2] Cellulosic feedstocks include dedicated bioenergy crops and crop residues, such as corn stalks and leaves, that are generally left in the field when grain is harvested. How the transition to advanced biofuel is accomplished can significantly affect, for better or worse, the environmental outcomes.

The vision presented here is known as Multifunctional Agriculture because it is designed to produce both agricultural goods and environmental benefits.[3] A key feature of this concept is often the inclusion of perennial crops and cover crops—sometimes called continuous living cover—that can enhance soil health and reduce dependence upon fertilizer and pesticides while also producing the food, feed, fiber, and fuel that society needs.

Key Concepts

- The dominant agricultural paradigm in much of the American Midwest is farming operations that produce corn and soybeans.
- This intensive row crop system is associated with environmental impacts, including soil erosion and depletion, loss of habitat and biodiversity, nutrient loss impacting surface waters and the Gulf of Mexico, and greenhouse gas emissions. Existing conservation practices for corn and soybeans are not sufficient to meet the nutrient reduction targets established to shrink the Gulf "dead zone."
- Perennial biomass crops can be sited and managed to produce harvestable biomass and reduce soil and nutrient loss. Polycultures of grasses, legumes, and other forbs can produce biomass and create wildlife and pollinator habitats.
- Perennial biomass crop systems can be part of a virtuous cycle of innovation to produce renewable energy and reduce agricultural use of fossil fuels and greenhouse gas emissions while meeting society's needs for agricultural goods.
- Multifunctional agriculture systems featuring perennial crops involve the co-production of agricultural goods and ecosystem services. In prime row crop areas, policies to provide incentives for water quality improvement, greenhouse gas reduction, and conservation benefits may be needed for economic viability.

To think creatively about how to achieve desirable change, lessons can be drawn from a selective look back at how farming changed in Illinois and neighboring states during the 20th century.

Back to the Future

A century ago, farms in this region typically grew corn, small grains (e.g., oats, wheat, barley), and hay, and managed pasture for livestock and draft horses. Soybeans, which had been brought to the United States from China many years earlier, were just beginning to attract interest as a forage crop and rotational legume. Charles Meharry was one of the soybean pioneers. He first planted soybeans on his Champaign County farm located near the University of Illinois campus in 1909, and, within a few years, began hosting field days on his farm with presentations by university scientists and extension specialists such as W.L. Burlison and J.C. Hackleman.[4] Adoption of the new crop was slow at first. In 1921, a total of 32,000 acres of soybeans were planted in the entire state of Illinois. Potential food and non-food uses of soybeans were coming to be recognized, but there were no industrial facilities for processing soybeans into animal feed or food products.

A. E. (Gene) Staley ran a corn milling company in Decatur, Illinois. In November 1921, Staley announced that, "In response to the general and urgent desire on the part of the farmers of Central Illinois," his company had decided to build "a plant for grinding and extracting the oil from the soya bean."[5] The next year, Illinois soybean acreage more than quadrupled to 135,000. Between 1922 and 1925, the Staley soybean plant operated intermittently, with shutdowns due to equipment problems, limited quantity, or poor quality of beans. Staley persevered and overcame these hurdles. The company's research department developed many new uses for soy oil and meal.

Soybean production, markets, and uses grew steadily from the mid-1920s into the 1940s, changing the Midwestern landscape and agricultural economy. While many other individuals and organizations contributed to this growth, Charles

Meharry, William Burlison, and Gene Staley stand as suitable exemplars for the essential roles of farmer, scientist, and industrialist, respectively.

As soybean acreage climbed, farm mechanization reduced the need for oats and hay to feed draft horses. Through the 1940s, beef cattle and dairy cows remained an integral part of agriculture, even in prime row crop areas. But that was about to change, driven in large part by a truly disruptive technology—manufactured nitrogen fertilizer.

Nitrogen Fertilizer and Grain-only Farming

The Haber-Bosch process, named for its inventors Fritz Haber and Carl Bosch, uses high temperatures and pressures (and therefore high energy) with catalysts to combine atmospheric nitrogen with hydrogen from natural gas (methane) to form ammonia, which, when applied to the soil, is readily available to plants. Prior to Haber-Bosch, conversion of atmospheric nitrogen gas to biologically-available forms that are essential for the creation of proteins was largely limited to biological nitrogen fixation by soil bacteria often associated with leguminous plants. The Haber-Bosch process was used to manufacture nitrogen-based munitions during World War II. As the U.S. returned to a peacetime economy, some munitions plants switched over to production of inorganic nitrogen fertilizers, and plants dedicated to ammonia production were built on a scale that would eventually increase the amount of biologically reactive nitrogen globally by 50 percent.[6]

Michael Pollan described the implications of manufacturing nitrogen fertilizer using "prodigious amounts of electricity" and natural gas: "When humankind acquired the power to fix nitrogen, the basis of soil fertility shifted from a total reliance on the energy of the sun to a new reliance on fossil fuel… What had been a local, sun-driven cycle of fertility, in which the legumes fed the corn which fed the livestock which in turn (with their manure) fed the corn, was now broken."[7]

Ruth DeFries called this a pivot point that, "smashed open the bottleneck of soil fertility."[8] Inexpensive nitrogen fertilizer and new hybrid corn varieties caused corn yields and total grain production to skyrocket and also affected what people ate. "More grain meant more animals at the trough, which meant more people enjoying meat, eggs, and dairy more often… There is no mistaking that the Haber-Bosch process was one of humanity's all-time pivot points, changing diets and ratcheting up the number of mouths that the world's supply of food could feed." In beef feedlots and other animal feeding operations, cattle, swine, and poultry ate primarily grain-based rations. With manure no longer essential for corn production, many farmers in parts of Illinois, Iowa, Indiana, and neighboring states became corn-soybean specialists, supplying grain to livestock operations in areas less suited to annual row crops. Pasture and livestock declined sharply in areas with fertile prairie soils and plentiful rainfall.

Figure 1 shows crop acreage in three Central Illinois counties since the 1920s. The transition from mixed grain-livestock operations to grain-only farms after World War II represented a paradigm change in U.S. agriculture. By 1970, crop patterns were much like they are today. Corn and soybeans dominate the Midwestern landscape, with acreage of each crop fluctuating in response to market and policy signals. Perennial forages and sod-forming small grains account for a small fraction of total farm acres. In the three-county area of Central Illinois, which is representative of prime cropland in the Upper Midwest, corn and soybeans have accounted for at least 95 percent of total reported crop and pasture acreage since 1978. This large-scale conversion of vegetation on the landscape has resulted in unintended and undesirable environmental consequences: degraded water quality, greenhouse gas emission, and loss of biodiversity.

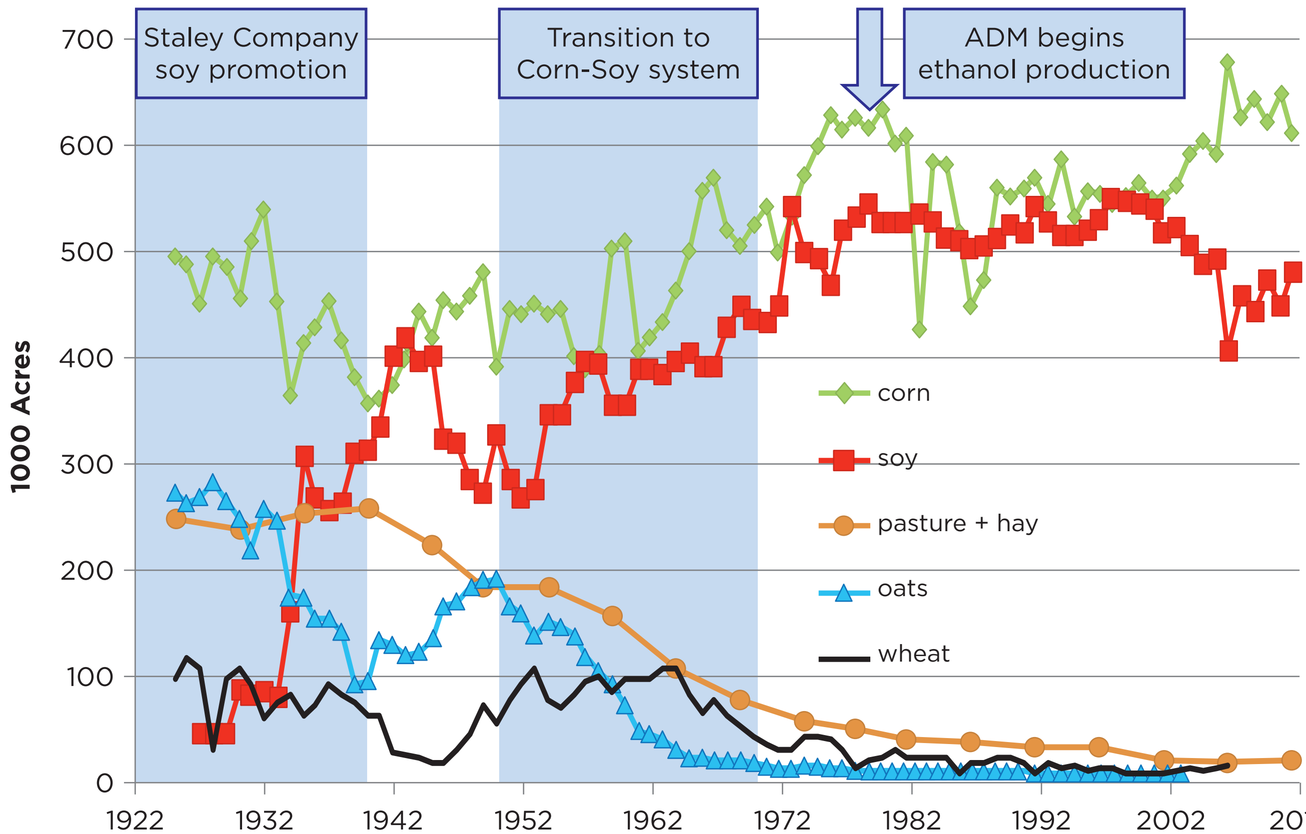
Managing Environmental Impacts

In the half century since grain-only farming became dominant, the impacts of intensive row crop agriculture on soils, habitat, and water quality have been recognized and federal policies have attempted to mitigate these impacts.

In an effort to alleviate the negative environmental impacts of corn-soybean agriculture, the 1985 Farm Bill introduced Sodbuster, Swampbuster, and Conservation Compliance provisions, and established the Conservation Reserve Program (CRP). Subsequent Farm Bills added new conservation programs.[9] CRP and similar programs provide financial incentives to take land out of annual row crop production and plant perennial vegetation for wildlife habitat, clean water, and soil conservation. In prime corn-soy areas, land enrolled in CRP accounts for much of the perennial cover on the farm landscape, but usually represents a small percentage of farmland—less than 1.5 percent in the three-county Illinois illustration. With limited exceptions, CRP rules prohibit harvesting hay or grazing enrolled acreage.

In addition to Farm Bill conservation programs administered by the U.S. Department of Agriculture (USDA), federal Clean Water Acts since 1972 have created a framework administered by the Environmental Protection Agency (EPA) to address "nonpoint source pollution," including agricultural runoff. Point sources, such as municipal and industrial wastewater treatment plants, are regulated and must meet pollutant limits in their effluent discharge permits. Except for large animal feeding operations, nonpoint sources are addressed through the promotion of voluntary Best Management Practices, such as

Crop Area in Macon, Piatt, Champaign Counties, IL



Greg McIsaac

Figure 1. Crop area changes in central Illinois, illustrating the rise of soybeans in the 1920s and '30s and the shift to grain-only farming in the 1950s and '60s.

grassed waterways, terraces, and nutrient management plans

While some conservation programs provide incentives for planting perennial vegetation (but not harvestable crops) for conservation, other farm and energy policies have provided incentives for planting more acres of corn and soybeans. Since 1980, federal tax credits, import tariffs, and more recently, the Renewable Fuel Standard have supported the domestic production of ethanol and other biofuels. More than one third of the US corn crop has been used for ethanol production in recent years.[10] Rather than changing the agricultural landscape, incentives for corn ethanol and soy biodiesel have largely reinforced the corn-soy system, but the mandate for second-generation biofuels has the potential to support a more diversified landscape by creating a market for perennial bioenergy crops.

Current federal policy is designed to drive development and deployment of technologies to produce second-generation biofuels from cellulosic feedstocks, including crop residues, perennial grasses, and woody biomass, rather than from corn and soybeans. The 2007 Energy Bill expanded the Renewable Fuel Standard to mandate 36 billion gallons per year by 2022, including 16 billion gallons of cellulosic biofuel.[11] The 2008 Farm Bill introduced incentives for production of cellulosic feedstocks, including perennial biomass crops. Macro-analyses of scenarios to achieve federal bioenergy policy goals, such as the "Billion-Ton" reports issued by the U.S. Department of Energy (DOE), typically conclude that corn stover—the stalks, leaves, and cobs left in the field when corn is harvested—will be the major cellulosic feedstock produced in Illinois and much of the Corn Belt.[12] If this comes to pass, increased production of cellulosic biofuels may, like first-generation biofuels, reinforce the corn-soy system, rather than leading to significantly more continuous living cover on the land.

It is noteworthy that the latest Billion-Ton report issued in July 2016 pays more attention to perennial energy grasses and short-rotation woody crops.[13] DOE has recently held workshops and issued grants to address water quality and other benefits of sustainable landscape design for bioenergy feedstock production. The USDA is also supporting research on synergies between bioenergy and enhanced water quality. These actions suggest that executive branch agencies

Steve John

University of Illinois graduate student Andy Wycislo, in orange shirt, talks with visitors to the Agricultural Water Institute University of Illinois bioenergy grass plots at the Farm Progress Show in Decatur, Illinois.

are thinking about the challenge of developing multi-objective policies and programs explicitly intended to combine renewable energy targets with additional environmental goals.

A New Paradigm

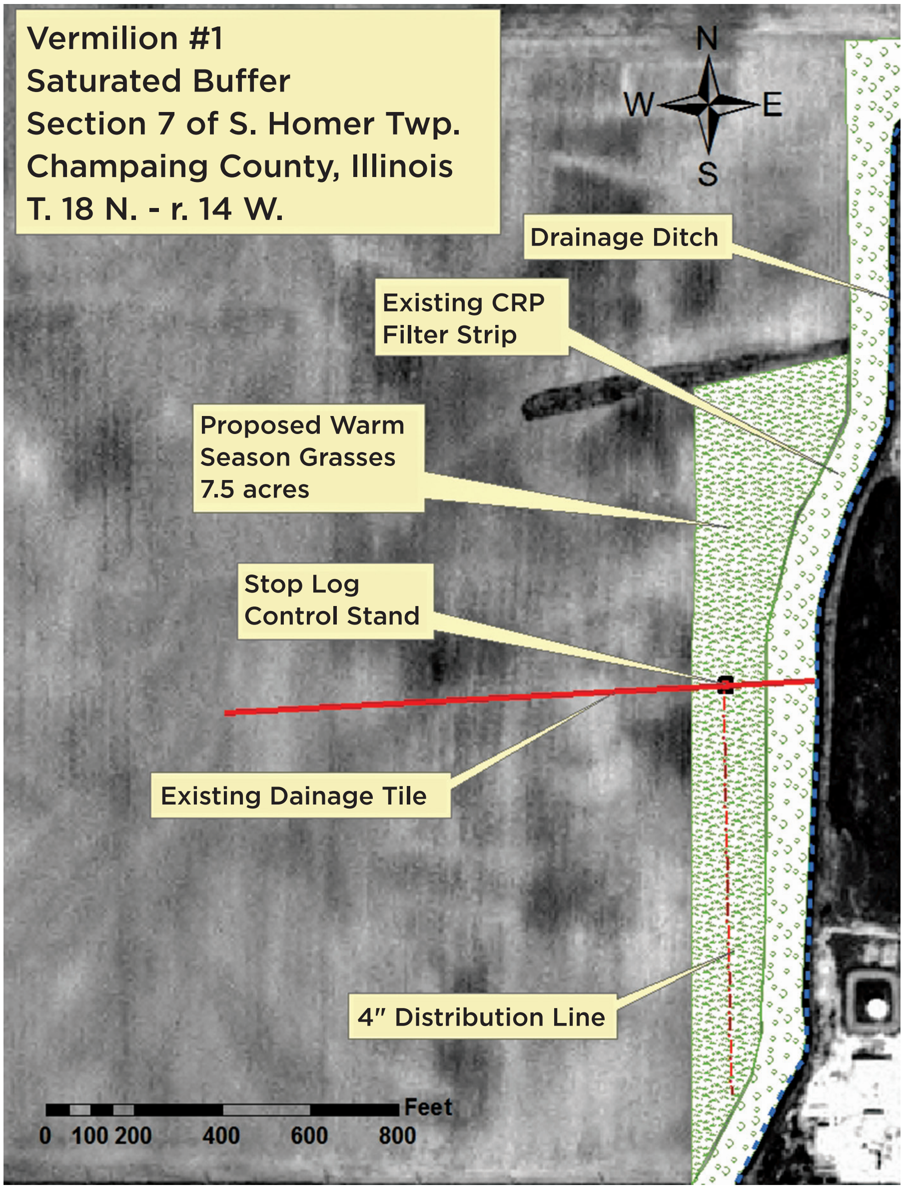
A new agricultural paradigm could be designed to address two pressing environmental concerns facing the U.S. today. One significant driver is the nutrient enrichment of surface waters causing algal blooms and hypoxia in estuaries and coastal waters, such as the northern Gulf of Mexico. Under pressure from the EPA, states in the Mississippi River Basin have developed nutrient loss reduction strategies that aim to reduce nitrogen and phosphorus in rivers by 45 percent. To meet this target in Corn Belt states, including Iowa, Illinois, and Minnesota, significant amounts of row-crop land need to incorporate cover crops or be converted to perennial crops (i.e., adopt continuous living cover).

A second, and arguably more urgent driver is the complex, interconnected set of issues associated with the reduction of greenhouse gas emissions, adaptation to climate change, and the shift from fossil fuels to renewables. EPA estimates that nine percent of total U.S. greenhouse gas emissions are from the agriculture sector, with more than half of that represented by nitrous oxide (N_2O) from agricultural soils.[14]

Our argument, in brief, is that implementation of standard conservation practices for reducing nutrient losses from annual row crops is not a cost effective approach to reducing nutrient loss and shrinking the greenhouse gas footprint of agriculture. The nature and magnitude of these challenges call for consideration of solutions outside the current corn-soy paradigm. Agricultural systems featuring perennial biomass crops offer a promising approach to address these concerns, and also enhance other aspects of U.S. agriculture, food, and energy systems.

The model of paradigm change set forth by Thomas S. Kuhn for the physical sciences offers a useful way of thinking about transformational change.[15] A generally-accepted scientific paradigm effectively limits the set of questions and solutions considered by scientists. A paradigm change occurs when they encounter anomalies that defy explanation within the current paradigm, and begin to look at problems from different perspectives and explore alternative solutions. Kuhn describes a scientific revolution as a change in world view.

Transformational change in economic sectors results from a variety of causes that may or may not involve deliberate efforts to solve thorny problems. Today, as society addresses major issues, including hypoxia and climate change, it is time for scientists and policy makers to work with farmers, industry, and other stakeholders to chart a course toward an improved agricultural future.



Tim McMahon, AWI

Preliminary layout by the Agricultural Watershed Institute for proposed harvestable saturated buffers to produce saturation-tolerant forage or bioenergy crops and reduce nitrate loss from crop fields via drainage tiles.

Next Steps

So how to begin? A Multifunctional Agriculture paradigm featuring perennial crops and farming systems can meet society's needs for agricultural goods and also improve environmental, social, and economic outcomes. To start making the case, consider that perennial biomass crops, including grasses, forbs, and short rotation trees can help to reduce nutrient loss, reduce greenhouse gas emissions, and enhance ecosystems in agricultural areas.

Nearly all water quality improvement plans for agricultural watersheds focus on adoption of conservation practices and implicitly assume there will be little or no change in what crops are grown over an implementation timeline stretching 20 years or more into the future. Some state nutrient strategies note that converting from annual to perennial crops is an effective way to reduce nutrient loss from farmland, but do not project a significant increase in perennial crop acreage.[16,17]

As Midwestern farmers and conservation agencies address nutrient loss impacting drinking water supplies and the Gulf of Mexico, nitrate loss from tile-drained farm fields poses a special challenge. Subsurface drainage tiles are installed in level, or nearly level, soils where ponding or a high water table would otherwise inhibit field operations and row crop production. This is the case in much of the fertile prairie soils of Illinois, Iowa, and Minnesota. Drainage tiles carry nitrate under vegetated buffers designed to remove pollutants from surface runoff, which largely defeats the purpose of the buffer. Rather than draining water and nitrate from every acre, planting perennial crops that better tolerate saturated conditions could reduce nitrate pollution and produce biomass for animal feed or cellulosic bioenergy. The ability of some perennial forage and bioenergy crops to tolerate wet conditions makes it feasible to design harvestable saturated buffers or seasonal wetlands in which nitrate that would otherwise reach surface waters, fertilizes a biomass crop lower on the landscape.

Scientific research and practical experience from working farms are needed to assess the potential of new cropping systems and bioenergy technologies to reduce greenhouse gas emissions from the agricultural and energy sectors. The paradigm shift concept offers a lens through which to consider alternative agricultural futures. The global challenge of climate-related mitigation and adaptation calls for a deep rethinking of agriculture. Perennial cropping systems, including grass-legume polycultures producing animal feed and bioenergy feedstock, can be a first step in a virtuous cycle of innovation to produce renewable fuel, reduce agricultural use of fossil fuels, and reduce greenhouse gas emissions from agricultural land, all while meeting society's needs for agricultural goods. Field- and watershed-scale studies of multifunctional perennial systems can provide a sound basis to model food-energy-water nexus scenarios, and

Paul Wever, Chip Energy Inc.

Participants in a Department of Energy Sustainable Bioenergy Landscapes workshop tour a prototype biomass processing facility under construction by Chip Energy in Goodfield, Illinois. The facility is designed to process 100 tons per day of biomass feedstocks (bioenergy crops, crop residue, and woody biomass) for shipment to end users. Recycled shipping containers form the walls of the facility and will store chopped and densified biomass.

to design policies to achieve multiple environmental and social objectives.

Existing Farm Bill conservation programs provide models of public payments for ecosystem services. They also illustrate the basic fact that agriculture designed to produce environmental benefits as well as harvestable crops inherently involves synergies and trade-offs. Through CRP and related programs, the USDA essentially "rents" farmland and takes it out of agricultural production in order to obtain the soil, water, and wildlife benefits of perennial vegetation. The newer Conservation Stewardship Program provides incentives for whole farm conservation activities, such as cover crops and rotational grazing, "built on the belief that we must enhance natural resource and environmental protection, as we simultaneously produce profitable food, fiber, and energy."[18] A large-scale shift to increase harvestable perennial crops could combine elements of each model. On-farm research and development can evaluate synergies and trade-offs among agricultural goods and a menu of ecosystem services, thereby providing a scientific basis for next-generation farm programs that increase the net societal benefits.

While there is an expanding body of research on the benefits of more perennial-based agriculture, bringing about an agricultural transition comparable in scale to the post-war shift to grain-only farming is clearly an ambitious undertaking. Green Lands Blue Waters (GLBW) is a consortium of university scientists and nonprofits with a mission to support the development of and transition to multifunctional farming systems featuring more perennial and cover crops.[19] GLBW members and partners see this as a long-term project for the transformation of the agricultural landscape and food system. Member organizations are concentrated in Minnesota, Iowa, and Illinois, with active partners in other states. Collaboration among farmers, scientists, and other stakeholders to expand markets and develop new enterprises based on perennial cropping systems is a key feature of the GLBW theory of change.

The GLBW scope encompasses several categories of continuous living cover: perennial grains, perennial forage, perennial biomass, agroforestry, and cover crops. These categories overlap synergistically. One noteworthy example is that grasses and legumes can be managed to provide both forage and bioenergy feedstock. The scale of GLBW's long-term transformational vision is grand. Wes Jackson, one of the co-founders of GLBW, has proposed a "50-Year Farm Bill" during which annual row crops would be largely replaced by perennial versions of wheat, rice, corn, soybeans, and other annual grain crops.[20] Aided by GLBW, the Land Institute in Salina, Kansas, founded by Jackson in 1976, is in the process of improving and expanding the plantings of its Kernza™ intermediate wheatgrass as the first perennial grain to move from research institutions to working farms and restaurant tables.

Clearly, perennial biomass crops offer opportunities for production of environmental services, as well as agricultural goods. This fits squarely within the GLBW vision, but there are major obstacles to wide adoption, with market development and farm economics high on the list. What follows are preliminary thoughts on a collaborative initiative to overcome the obstacles.

The 20th century agricultural landscape transformations described took place largely in response to a new crop with new uses and markets (soybeans) and technological innovations (mechanization and manufactured fertilizer). Government policy, including ethanol subsidies, significantly affected crop choices and farm economics. Lessons from this history are instructive for a potential 21st century transformation involving bioenergy crops. Farmers, entrepreneurs, and established industries—the Meharrys and Staleys of today—will be key participants if this change is to happen. Policy innovations will be needed to support the transition.

Expanding Markets

The soybean story highlights the essential role of farmer-pioneers willing to try new crops and see how they fit into a production system and farm enterprise. New crops can pose a chicken-and-egg problem. Why plant a crop for which there is no existing market? Why invest in facilities to process or use a crop that hardly anyone is growing? Meharry and others began growing soybeans as a forage crop and rotational legume (adding nitrogen for the following corn crop) more than a decade before Staley provided an industrial outlet to process soybeans for food and non-food uses. Today, switchgrass, Eastern gamagrass, and other native grasses and forbs are grown for forage and conservation purposes. Biomass crops, such as Miscanthus, that have little or no forage value, can be used for animal bedding or mulch. In the early stages of a new paradigm featuring perennial crops, forage and bedding markets can be a pathway for testing coproduction of grass biomass and ecosystem services before bioenergy markets develop. Even after markets are in place, two-cut systems may be desirable to produce both feed and fuel. Some grasses can be harvested in spring or summer for forage, and the regrowth harvested after senescence as bioenergy feedstock.

As with soybeans, both production-side "push" and market-side "pull" are needed, that is, both Meharrys and Staleys. For illustration, here are a few of the entrepreneurs now seeking to fill a niche in the start-up of a bioeconomy using dedicated perennial crops. Fred Circle, of FDC Enterprises, has developed new methods for the establishment of bioenergy grasses and supply chain logistics for harvest, storage, pre-processing, and transport to energy end users. Paul Wever, of Chip Energy, is constructing a proof-of-concept facility in Illinois to pre-process waste stream biomass and dedicated biomass crops to meet end users' specifications. One day, such biomass conversion facilities can take their place alongside grain elevators as part of a cellulosic bioenergy infrastructure. Rudi Roeslein, of Roeslein Alternative Energy, is constructing a large-scale project in Missouri to mix prairie biomass with hog manure in an anaerobic digestion facility producing renewable natural gas. He was a leader in the formation of the Midwest Conservation Biomass Alliance to promote native grassland polycultures for commercial use plus wildlife habitat.

University researchers and university-sponsored projects are also paving the way for commercial use of grass biomass. Examples include a Michigan State University team working on ammonia fiber expansion as a pretreatment process for cellulosic biomass for use as animal feed or bioenergy feedstock, and a University of Iowa project to co-fire coal with Miscanthus to heat the campus.[21,22]

For perennial biomass crops to assume a significant role, bioenergy markets as well as forage markets need to ramp up. The Renewable Fuel Standard focuses on large-scale production of cellulosic transportation fuels, but small-to-medium-scale heat or Combined Heat and Power systems may be important uses for bioenergy grasses, both initially and in the long-term. Properties of herbaceous biomass, such as its relatively high ash content, pose a design challenge for densification equipment and heating appliances to handle grass and meet EPA air quality standards. Reliable, affordable equipment would facilitate on-farm biomass space heating and grain drying and biomass-fueled district heating systems. Community Supported Energy farmers or co-ops could employ a modified version of the Community Supported Agriculture business model.

Corn and soybean growers need not feel threatened by the prospect of perennial biomass crops integrated into farm fields. Perennial farming systems can share the agricultural landscape quite compatibly with corn-soy production. Strategic placement of perennial crops, combined with drainage system modifications, can capture and use nutrients lost from row crop fields. Even in prime cropland, there are erodible slopes, poorly drained depressions, and irregularly-shaped parcels where perennial biomass crops would make economic and environmental sense. In the future, grain farmers and grass farmers could share a landscape managed to produce annual (and eventually perennial) grain, perennial forage, and bioenergy crops plus clean water, wildlife, pollinators, and healthy soils with increased organic carbon.

Scientists interested in the future of agriculture have modeled alternative scenarios in two Iowa watersheds. They found that scenarios with more perennial crops can produce significant environmental benefits including enhanced water quality and biodiversity, and that farmers are likely to accept them if policies are adopted to maintain farm income.[23] Research and demonstration projects are needed at the watershed and fuelshed scales to move beyond modeling exercises to real-world assessments of a perennial-based paradigm. Experimental watersheds or "landlabs" have been proposed as places where farmers, universities, nonprofit organizations, government agencies, private businesses, and other stakeholders test new cropping systems and create agricultural enterprises with high performance in economic, environmental, and social terms.[24] Experimental watersheds can also test policy innovations to inform future farm and energy legislation.

Perennial agriculture integrated with annual crops represents a promising new paradigm well suited to sustainable coproduction of agricultural goods and ecosystem services in a climate and energy-constrained world. But, there are significant challenges that must be overcome. Twenty years—roughly as long as it took for the post-war shift to grain-only farming—seems a reasonable time frame to achieve a comparable level of adoption of perennial biomass crops. While 20th century landscape transitions offer useful lessons, development and wide adoption of multifunctional perennial cropping systems will involve additional complexity, notably including economic and policy innovations to internalize environmental costs and benefits that are now unpriced.

Perennial biomass crops represent the only source of renewable energy that can also provide a suite of landscape-based environmental benefits including, but not limited to, reduced nutrient loss and greenhouse gas emissions. Just as soybeans became an important new crop with new uses nearly a century ago, perennial biomass crops grown for animal feed, bioenergy, and bio-based products can become part of the 21st century agricultural landscape. Collaboration among farmers, scientists, and industry—with an important role for policy makers—can make it happen.

Renewable energy from dedicated perennial crops that also reduce agricultural use of fossil fuels and greenhouse gas emission from cropland can be included in future U.S. Nationally Determined Contributions under the Paris Agreement. However, U.S. President-elect Donald Trump has stated his intention to withdraw from that global agreement. With U.S. government participation in climate efforts and perhaps other environmental initiatives in jeopardy, the role of pioneering farmers, business leaders, researchers, investors, and philanthropists in the early years of a transition to more perennial cropping will be even more essential. Stakeholders that value the climate, energy, water, soil, and wildlife benefits of perennial biomass crops can demonstrate sustainable production, develop uses and markets, and advocate for policies to support wide adoption.

A landscape transformation comparable in scale to the "big ratchet" associated with Haber-Bosch and hybrid corn would bring perennial grasslands back to the level of pasture and hay acreage circa 1950 in equilibrium with the existing corn-soy system. In the prime croplands of east-central Illinois, that would be about 10 to 15 percent of farmland acreage. That level of land-use change, combined with naturalization of agricultural drainage made possible by saturation-tolerant perennials, can be expected to go a long way toward meeting the 45 percent nutrient loss reduction targets established to reduce hypoxia in the northern Gulf of Mexico. A virtuous cycle involving breakthroughs in production, processing, uses, and markets for perennial biomass crops, plus advances in perennial grains and agro-forestry food production, could push the perennial-annual equilibrium point even higher, with major opportunities to reduce agricultural sector greenhouse gas emissions.

The 20-year Plan

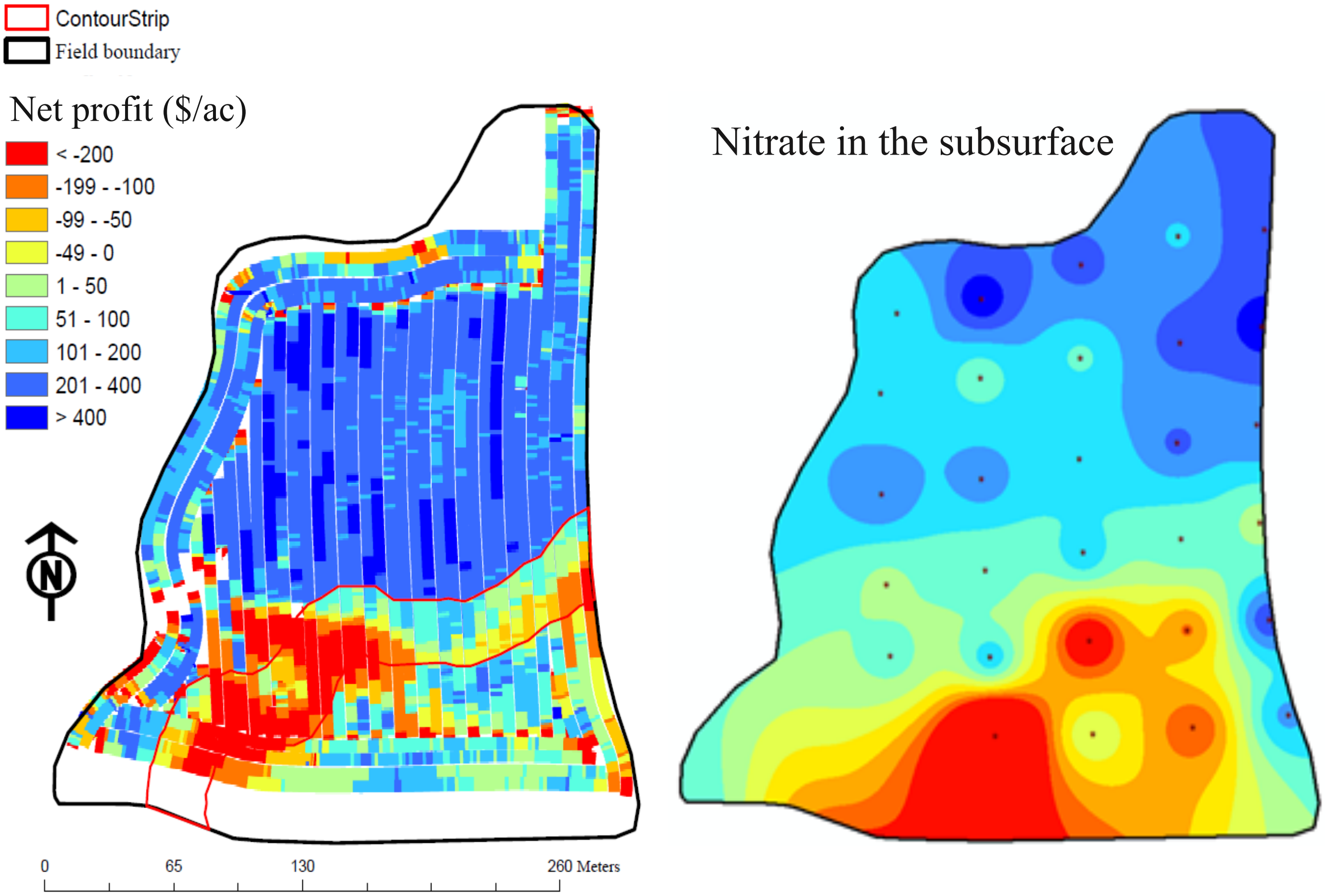
The first ten years of the transition period are seen as a time to overcome technological challenges, explore agroecological synergies and trade-offs, demonstrate perennial farming systems at field and landscape scales, create supply chains and profitable enterprises at a range of scales, and adopt policies and programs to support the multifunctional agriculture paradigm.

Here are some broad-brush thoughts on goals, actors, and actions:

Years 1 to 5

Conduct research and development on multifunctional perennial crops and systems.

- University, government, NGO, and corporate researchers continue and expand work to improve yield and other attributes of perennial biomass crops grown in monocultures or polycultures.
- Pioneering farmers collaborate with researchers and NGOs to demonstrate and evaluate on-farm performance of forage/bioenergy crops and modified drainage systems to achieve reductions in nutrient losses and greenhouse gas emissions, and improvements in soil health, wildlife habitat, and other ecological functions.



Cristina Negri, Argonne National Laboratory

Comparison of intrafield net profitability and subsurface nitrate by Argonne National Laboratory for a research site near Fairbury, Illinois. This type of analysis is beginning to be used to integrate perennial bioenergy crops (Contour Strip) into corn-soy fields to produce cellulosic feedstock while improving both economic and environmental outcomes.

- With NGO and university assistance, producers implement local bioenergy demonstration projects to provide replicable models of Community Supported Energy, farmer-owned bioenergy cooperatives, and related business enterprises.

Make equipment available and increase market development.

- With government and philanthropic support, for-profit businesses and mission-driven entities, such as Benefit Corporations (B Corps), formed for profit and environmental goals develop equipment and systems to process and use grass biomass for small- to medium-scale heat or cogeneration.
- Large-scale cellulosic bioenergy enterprises partner with producers and other stakeholders to ensure that feedstock production meets sustainability standards.
- Innovative companies in the agricultural, energy, and manufacturing sectors assess opportunities to profit from production, processing, and use of perennial biomass crops for animal feed, bioenergy, and bioproducts.

Demonstrate integration of multi-functional systems with appropriate program and policy innovations.

- Scientists and economists use research results to add new perennial cropping and naturalized drainage systems to models, and to include multifunctional agriculture scenarios in plans to achieve water quality, renewable energy, and climate-related objectives.
- With public, private, and philanthropic funding, watershed projects engage local stakeholders, researchers, NGOs, and business entities to serve as landlabs to test sustainable landscape design, biomass supply chains, energy conversion technologies, and policy innovations.

Years 6 to 10

Ramp up multifunctional perennial systems.

- Research continues on improved perennial crops and polycultures for coproduction of bioenergy feedstock and ecosystem services.

- Multifunctional perennial crops and systems gain acceptance, and begin to be widely promoted by universities, conservation agencies, and crop advisors.

Ramp up equipment, supply chains, markets, and enterprises.

- For-profit and mission-driven businesses take the lead to improve equipment and supply-chain logistics to use grass biomass and short rotation coppice woody biomass for heat and cogeneration of electricity.
- The number and visibility of Community Supported Energy operations, bioenergy cooperatives, and related enterprises increases.
- Growing numbers of large and small enterprises make the use of perennial biomass crops for a variety of energy, animal feed, and bio-based product applications an integral part of their business model.
- More cellulosic biorefineries and related enterprises come online, using perennial feedstocks and applying the principles of sustainable biomass production and landscape ecology.

Incorporate multifunctional agriculture into plans, programs, and policies.

- Multifunctional agriculture landlabs continue to innovate to improve social, economic, and environmental outcomes, and to provide testing grounds for policy and program innovation.
- Knowledge gained from perennial biomass R&D is used to design programs and policies for inclusion in energy and agricultural legislation, implement state nutrient reduction strategies, and the U.S. nationally-determined contribution of greenhouse gas reductions under the Paris Agreement.

Years 10 to 20

Broadly, these years are seen as a period in which perennial-based multifunctional agriculture goes mainstream. If the action plan outlined above is successful, by around Year 10 the new paradigm should reach a tipping point beyond which increased adoption becomes self-sustaining and perennial crop acreage climbs in the S-curve characteristic of diffusion of innovations until a new annual-perennial equilibrium is reached. S

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Multifunctional Agriculture:
A New Paradigm of Mixed Cropping

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Solutions is a non-profit print and online publication devoted to showcasing bold and innovative ideas for solving the world's integrated ecological, social, and economic problems.

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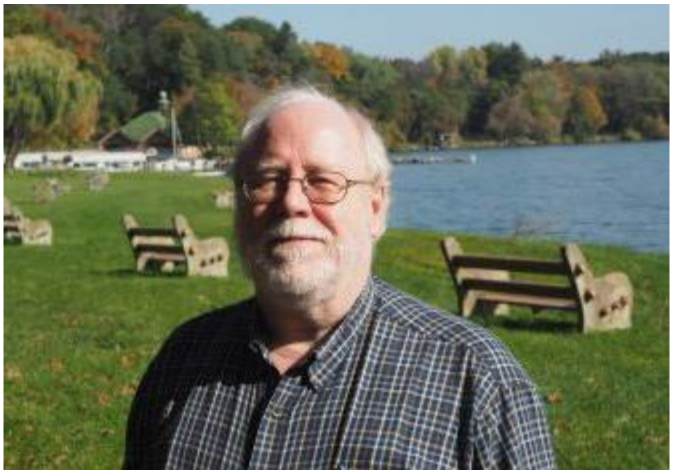

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AWI's mission is to conduct research and educational programs on practices and policies that improve water quality, maintain or restore ecosystem health, and conserve land and water resources in agricultural watersheds.

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