Rotating Crops, Turning Profits

How Diversified Farming Systems Can Help Farmers While Protecting Soil and Preventing Pollution

Union of Concerned Scientists

The midwestern United States is one of the world's most fertile and productive farming regions, but it is a landscape dominated by just two crops. Across the 12 states of the Corn Belt, corn and soybeans account for 70 percent of the planted acreage (NASS 2016a).[1]

But the farming system that produces these two commodity crops in such abundance has grown steadily less beneficial to farmers. In 2016 US corn and soybean growers achieved record-high harvests (NASS 2017); however, due to oversupply, prices farmers receive for these crops have plummeted, and US farm incomes were expected to be down for the fourth consecutive year, to their lowest levels since 2002 (Schnepf 2017). Moreover, as a result of prevailing farming practices, Corn Belt farmers are losing soil to erosion at unsustainable rates (Cox, Hug, and Bruzelius 2011), which threatens the long-term viability of their businesses.[2]

The dominant two-crop farming system also has negative consequences for rural communities and the environment. Corn and soybean production is a warm-season system that typically leaves the soil bare for as much as seven months of the year, and it frequently employs tillage (plowing) practices that exacerbate soil erosion.[3] These crops also often rely on heavy fertilizer use to boost productivity. With tilling, and with a lack of living roots in the ground year-round, excess nitrogen fertilizer escapes from soil into the air and into waterways. Nitrogen pollution from agriculture costs the nation an estimated $157 billion per year in human health and environmental damages (Sobota et al. 2015). Rural communities suffer many of the consequences; Iowa, for example, ranks high among states in the extent of surface water pollution from fertilizers, pesticides, and eroded soil. And the negative effects extend far beyond the Midwest. Corn Belt watersheds are major contributors to the annual nutrient-caused "dead zone" in the Gulf of Mexico (IDNR 2015; EPA 2013), and nitrous oxide emissions from agricultural activity comprise 5 percent of the United States' share of heat-trapping gases responsible for climate change (EPA 2014).

There is an urgent need for solutions that maintain farmers' productivity and profitability, protect the soil, and prevent air and water pollution. Recent research has shown that modified cropping systems can provide these solutions. A long-term study at Iowa State University has shown that transitioning Iowa farm acres from today's dominant warm-season, two-crop system to a more diverse system involving three or four crops grown throughout the year can increase crop yields and maintain similar per-acre profits (Davis et al. 2012). The Union of Concerned Scientists (UCS) performed additional analysis that indicates this system can provide additional benefits: reduced soil erosion, decreased runoff of pollutants that threaten the region's waterways and drinking water supplies in downstream communities, and lower emissions of heat-trapping gases to the atmosphere.

Is such a modified system scalable? Our research suggests that it is. Building on Iowa State's results with additional analysis of soil erosion outcomes and economic impacts, we found that these innovative cropping systems could be implemented on millions of acres in Iowa today, and expanded to tens of millions more acres over time. But it's not simple and will require policy shifts. Farmers who might adopt a modified farming system face challenges including financial and technical barriers as well as crop insurance and credit constraints. New and expanded federal farm policies are needed to help farmers overcome those barriers and reap the benefits of these systems. We offer policy recommendations for the US Department of Agriculture (USDA) and for Congress as it reauthorizes federal farm legislation, indicating key levers that policy makers can utilize to bring about more sustainably productive farming systems in the US Midwest.

Diverse Crop Systems in Iowa Maintain Farmers' Profits While Delivering a Range of Additional Benefits

Over a period of 15 years, Iowa State University researchers have investigated the effects of more diverse crop rotations—farming systems that include three or more crops rather than the usual one or two—on outcomes such as crop yields, profits, soil erosion, fertilizer use, and water pollution. The 22-acre experiment, located at a site in central Iowa called

Cover photo: Courtesy of Practical Farmers of Iowa

Marsden Farm, has tested the extent to which cropping system diversification can improve environmental outcomes without sacrificing crop productivity and profitability. Rotational farming systems have been used extensively and historically to maintain soil fertility and productivity, suppress pests, and increase yields (Bennett et al. 2012; Karlen et al. 1994), though the reasons for these multiple benefits have not always been fully understood. Modern science-based rotations are based on a fuller understanding of the ecological mechanisms at work, and the Marsden Farm experiment has added significantly to this knowledge (see box, p. 5) (Hunt, Hill, and Liebman 2017; Davis et al. 2012).

Starting in 2003, Iowa State researchers at the site have compared three rotation systems: the two-year corn-soybean system that is typical in the region today; a three-year system that adds a cool-season small grain (such as oats) with a cover crop of red clover that also acts as a "green manure"; and a four-year system that includes a small grain (again, oats) with a green manure of alfalfa, followed by a second year of alfalfa for harvest. The three- and four-year rotations, though not the norm in Iowa today, are viable farming systems found in the region and often include livestock that can make use of oats and alfalfa as feed and provide manure to fertilize the crops.

The researchers applied synthetic fertilizer at typical rates in the conventional two-year rotation, while applying a combination of composted cattle manure and lower rates of synthetic fertilizer in the longer rotations. Similarly, herbicides were applied at typical rates in the two-year rotation and lower rates in longer rotations.[4] Tillage practices differed among rotation systems.[5]

Key findings from Iowa State University's research for the period 2008–2015 include the following.[6]

- **Higher yields.** Corn yields per acre were 2 to 4 percent higher, and soybean yields 10 to 17 percent higher, in the three- and four-year rotations compared with the two-year corn-soybean rotation. The increase in corn yields was due to the addition of manure, while the increase in soybean yields was due to the addition of manure along with effects of the extended rotations that protect against plant disease (Hunt, Hill, and Liebman 2017).
- **Similar profits.** Net profit per acre was statistically similar across all three rotation systems (Hunt, Hill, and Liebman 2017).[7]
- **Reduced herbicide use.** The longer-rotation systems required 25 to 51 percent less herbicide use, which in

Laura Miller/Leopold Center for Sustainable Agriculture

Iowa State University researchers at the Marsden Farm site have compared the corn-soy cropping system pictured here with longer rotations including combinations of oats, alfalfa, and a red clover cover crop. The longer rotations generated higher yields and similar profits with less herbicide and fertilizer use.

turn reduced herbicide runoff effects in water by 81 to 96 percent (Hunt, Hill, and Liebman 2017).[8]

- **Reduced fertilizer use.** In the longer rotations, rates of synthetic nitrogen fertilizer application were 88 to 92 percent lower and combined synthetic and organic nitrogen fertilizer application rates were 43 to 57 percent lower[9] (Appendix 1; technical appendices are available on the UCS website at *www.ucsusa.org/RotatingCrops*).

Analysis: Scaling Up Diverse Rotation Systems in Iowa

The crop rotation systems tested in experimental settings in the Iowa State study offer a range of agronomic, environmental, and economic benefits for farmers and rural communities. However, it is important to know whether such benefits hold up at scale.

Converting large amounts of corn to a three- or four-year rotation would significantly decrease corn and soybean production, and the market could respond with a corresponding increase in prices that would provide an incentive for farmers to return to corn-soy (though the extent to which prices will increase may not be large due to the global corn market).[10] At the same time, expansion of longer-rotation systems would increase the acreage of oats and alfalfa, which currently make up less than 1 percent and 11 percent of the planted acreage in the Corn Belt, respectively (NASS 2016b), and an influx of small grains and alfalfa into the market would lower the prices farmers receive for these crops and constitute a disincentive for their cultivation. Given these supply-demand dynamics, we analyzed the magnitude and nature of a sustainable expansion of these systems that would maximize benefits to farmers over the long term.

In a two-step analysis, we modeled the reallocation of total corn acres[11] in 25 Iowa counties among the three rotation systems—corn-soy, corn-soy-oats, and corn-soy-oats-alfalfa—and then scaled up the systems across more of the state based on total land availability and rotation constraint (Appendix 2). This analysis accounted for changes in supply of various crops in the diverse rotation systems by assuming the increased use of oats and alfalfa for livestock feed.

Currently, market demand for oats and alfalfa is low, but lower prices due to increased supply of these commodities would likely drive livestock farmers to use these crops as substitutes for corn in livestock feed. There is precedent for this, as feed markets have shifted in recent years to take advantage of economical feed supplements generated as by-products of the corn ethanol spike (Appendix 3). And research and case studies have shown that 20 to 40 percent of corn in hog diets can be replaced with other small grains without affecting livestock weight gain. Our model assumed that initially a small percentage of today's feed demand for corn would be replaced by oats/alfalfa and the remaining cropland in Iowa would be planted under prevailing agricultural practices. We modeled different levels of feed substitution and found that approximately 10 percent livestock feed substitution in Iowa would be needed to stably implement diverse rotations in 25 counties (3.6 million acres) and thus ensure the range of beneficial environmental outcomes (Appendix 6 and Tables 1, 2, and A2.1).

We focused our analysis on Iowa; however, our results can be generalized throughout the Corn Belt.

Adoption of Diverse Rotation Systems on the Most Erodible Soils Would Produce Dramatic Benefits

For step 1 of our analysis, we hypothesized that modified cropping systems would achieve the most dramatic benefits from decreased soil erosion in regions of the state known to have the most fragile, erodible soils. Currently, corn production is concentrated and is most intensive in the central and northwestern parts of the state, where soils are deep and the landscape is rolling to flat. Erosion rates in these areas are low. However, despite having more fragile soils, other parts of the state are also farmed intensively with corn and soybeans, and this can lead to much higher rates of erosion. While data from the 2012 National Resources Inventory indicate that erosion for most soils in Iowa averaged above

> ***There is an urgent need for solutions that maintain farmers' productivity and profitability, protect the soil, and prevent air and water pollution.***


Matt Liebman/Iowa State University

The experiment at Iowa State University's Marsden Farm site, shown here, found a range of benefits from longer crop rotations. Our analysis shows that these benefits hold up at scale.

Ecological Farming Systems Can Achieve Multiple Benefits

Agricultural practices and systems involving diverse rotations of crops rely on the application of ecological knowledge, working in tandem with natural systems as much as possible (Shennan 2008; Anderson 2007; Robertson and Swinton 2005; Liebman and Gallandt 1997). Sometimes referred to as agro-ecological or regenerative systems, they rebuild and protect soils and other natural resources as they deliver economic benefits to farmers and communities. Such systems take maximum advantage of naturally occurring ecological interactions to maintain soils, nourish crops, and fight pests (Deming et al. 2007; Shea et al. 1998; Vereijken 1992).

These systems can improve soil structure (Raimbault and Vyn 1991), reduce carbon and nitrogen losses (Dinnes et al. 2002; Drinkwater, Wagoner, and Sarrantonio 1998), increase soil organic matter (Campbell and Zentner 1993), take advantage of natural processes that add nitrogen to the soil (Riedell et al. 2009), reduce the incidence and intensity of crop diseases (Ghorbani et al. 2008; Tilman et al. 2002) and weeds (Anderson 2005; Dyck and Liebman 1994), increase the numbers of beneficial soil microbes (Deng, Moore, and Tabatabai 2000; Bossio et al. 1998), and reduce farmers' dependence on fertilizers and pesticides derived from fossil fuels (Cruse et al. 2010).

The main nutrients supplied externally in such systems are animal manures, "green manure" (usually cover crops incorporated into the soil), and compost—all of which improve soil structure and add organic matter—as well as some synthetic inputs in small amounts. Nitrogen requirements in these systems are met with nitrogen released from decomposing plants and manure along with some synthetic fertilizer (Magdoff, Lanyon, and Liebhardt 1997; Morris, Blackmer, and El-Hout 1993; Fox and Piekielek 1988). Weeds are managed with small amounts of herbicides in combination with cultivation and other cropping practices that expose weeds to various stresses and induce mortality (Liebman and Gallandt 1997). By requiring smaller quantities of synthetic fertilizers and herbicides, such systems can reduce farmers' costs while also curbing contamination of critical water resources, which benefits communities downstream.

the USDA's five-ton-per-acre-per-year "tolerable soil erosion rate" (the amount that can be lost each year without reducing agricultural productivity), soil losses in some parts of the state are much higher (NRCS 2015a; Cox, Hug, and Bruzelius 2011). Moreover, although the USDA has defined a tolerable loss as five tons per acre, the best available science currently indicates that the actual soil replacement rate is closer to 0.5 ton/acre/year (Montgomery 2007), revealing a much higher percentage of Iowa's agricultural soils as vulnerable.

In 2007, farmland on more than 10 million acres eroded faster than the tolerable rate and on 6 million acres farmland eroded at twice that level. In some places, soil losses during rain storms were as high as 64 tons per acre (Cox, Hug, and Bruzelius 2011).

It is in these highly erosion-prone areas that adoption of well-managed longer crop rotations, in conjunction with reduced tillage, is likely to be particularly beneficial. We used Iowa State University's Daily Erosion Project model (Appendix 5) to predict how soil erosion would be influenced by converting dominant management practices (corn and soybeans) to either a three- or four-year crop rotation system. From the top 25 percent erosive watershed districts in Iowa, we selected the top 25 counties, which contained a vast majority of these watershed districts.[12] Because our objective was to measure the impact of diverse rotation systems outside the flat to rolling north-central Des Moines Lobe region where the Iowa State study was conducted, and because tillage is a major driver of soil erosion in more hilly locations, our analysis assumed the use of no-till practices in the more diverse rotations. In this way, our modeled system differed from the Iowa State system, which used tillage in its diverse rotations.

We then asked the question, "Could farmers implement diverse no-till crop rotations on the acres currently planted with corn in the most erodible counties without high corn and soy prices driving them back to the existing system?" To answer this, we considered the average planted acreage of corn in those counties during the period 2008–2015 and applied an economic model (Appendix 2). Our analysis showed that adoption of the diverse rotation systems on 3.6 million acres—15 percent of Iowa's croplands—across the state's most erodible acres would have a dramatic effect on soil health in those regions (Table 1).

Lynn Betts/USDA

Fields left bare between crops lose topsoil and wash fertilizers and other pollutants into streams when heavy rains occur. Here, erosion is seen on an Iowa field after a spring rain, before young corn plants are established.

TABLE 1. Soil Erosion before and after Conversion to Longer Rotations—Top 25 Erodible Counties in Iowa

	Base (tillage)	Corn-Soy-Oats (no till)	Corn-Soy-Oats-Alfalfa (no till)
Average Soil Erosion Rate (tons/acre)	10.39	0.84	0.93
Drop in Soil Erosion (tons/acre)		9.54	9.46
Percentage Decrease in Soil Erosion		91.89%	91.04%

Note: All numbers reported are soil delivery rates from the Daily Erosion Project Model for the period 2008–2015. See Appendix 5 for methodology used to generate these results.

SOURCE: IOWA STATE UNIVERSITY'S DAILY EROSION PROJECT MODEL (ISU 2016).

The adoption of the diverse rotation systems on 3.6 million acres of Iowa's most vulnerable agricultural land would produce the following benefits *in addition to the net profits and yields found in the Marsden Farm study*:

- **Dramatically reduced soil loss**. The no-till diverse rotations[13] reduced soil erosion by 91 percent compared with tilled corn-soy (Appendix 5 and Table 1).

- **Reduced fertilizer runoff.** Reduced erosion means reduced runoff, and as a result of this reduced runoff of soil and fertilizers, taxpayers and downstream communities would save $196 million to $198 million annually in surface water cleanup costs (Appendix 6 and Table 2, p. 8).

- **Reduced global warming emissions.** Reductions in fertilizer use and the addition of soil organic matter in the diverse rotations would also achieve significant improvements in global warming impact. Society would realize reductions in nitrous oxide emissions from reduced nitrogen fertilizer application valued at $23 million to $27 million annually and carbon sequestration benefits valued at $51 million annually (Appendix 6 and Table 2).

Thus, adopting diverse rotations without tillage on the most erosive cropland (3.6 million acres) in Iowa would likely result in significant economic and environmental benefits.

Rotation Systems Could Be Further Expanded across Iowa over Time

For step 2 of our analysis, we used the same economic model to determine the extent to which Iowa's farmers could scale up this system across the state, beyond the highly erodible acres described above, especially if markets for small grains and alfalfa were expanded through further substitution for corn in livestock feed rations. In order to determine the amount of acreage that could be converted to a corn-soy-oats or corn-soy-oats-alfalfa rotation system, we asked the question, "On how many Iowa crop acres could we implement these longer rotations and achieve profitability without high corn and soy prices driving farmers back to the existing system?"

While some of the increased oat and alfalfa production can be absorbed by increased demand over time, absorbing the yields from the entire potential acreage into national markets would be challenging.[14] Our model indicated that in a scenario of statewide conversion to the new system, rising corn and soybean prices would drive farmers back to the current two-crop system in short order.[15] Therefore, we constructed a scenario to determine the proportion of Iowa cropland that could realistically be converted to a more diverse rotation without that result. We assumed that the remaining cropland would be planted under prevailing agricultural practices (Appendix 4). Currently, demand for oats/alfalfa is low, but experience has shown that new uses[16] will be developed for excess production of low-priced commodities (Appendix 3). Therefore, we expect that over time, as farmers see the substantial economic and environmental benefits of diverse rotations and increase adoption, new uses will be found for the additional small grains produced by this rotation system. We modeled the replacement of some of today's feed demand for corn with oats/alfalfa, at levels between 20 percent and 40 percent (Appendix 4). We then

[Reduced runoff of soil and fertilizers would save taxpayers and downstream communities $196 million to $198 million annually in surface water cleanup costs.]

TABLE 2. Annual Environmental Benefits from Longer Rotations—Top 25 Erodible Counties in Iowa

	Corn-Soy-Oats	Corn-Soy-Oats-Alfalfa
Acres Converted	3.65 million	3.65 million
CO_2 Equivalent Reductions[a]	0.17 ton/acre	0.20 ton/acre
Reduction in Emissions[b]	0.64 million metric ton	0.75 million metric ton
Dollar Value of Reduced CO_2 Emissions[c]	$23.15 million	$26.84 million
CO_2 Sequestered[d]	1.42 million metric tons	1.42 million metric tons
Dollar Value of Carbon Sequestered[e]	$51.19 million	$51.19 million
Savings in Surface Water Cleanup Costs[f]	$198.01 million	$196.16 million

a Results reported are from the nonlinear method. See Appendix 6 for methodology.
b Estimated as CO_2 equivalent reductions (ton/acre) × acres converted to corn-soy-oats/corn-soy-oats-alfalfa.
c Estimated as reduction in emissions × social cost of carbon ($36/ton) (EPA 2016).
d Though the rates of carbon sequestration from different agricultural practices are variable and still uncertain, we used data that suggest that carbon sequestration with conservation tillage could be an average of 0.50 metric ton/acre of CO_2-equivalent and with crop rotation could be an average of 0.29 metric ton/acre of CO_2-equivalent (The Nature Conservancy 2016). We used the average of these two numbers (0.39 metric ton/acre) of CO_2-equivalent. Thus, CO_2 sequestered is estimated as 0.39 × acres converted.
e Estimated as CO_2 sequestered × social cost of carbon ($36/ton).
f Calculated using Natural Resources Conservation Service estimates that for each ton of prevented soil erosion, surface water cleanup costs are reduced by $5.69 (2007 estimate was $4.93/ton; we updated to 2016 dollars) (NRCS 2009).

estimated the new demand for corn, soybeans, oats, and alfalfa and experimented with different acreage levels (given different land availability constraints) based on average yields of corn, soybean, oats, and alfalfa that would meet that demand (Tables 3, 4, A2.2, and A2.3).

Under these scenarios, we found that:

- Diverse crop rotations could be scaled up over time to **20 to 40 percent of Iowa's farmland**—to 5 million to 11 million acres (depending on whether a three-year or four-year rotation is implemented)—without driving farmers back to predominantly corn-soy.
- Again, tillage was a major factor in soil loss. The use of **no-till longer rotations reduces soil erosion by 88 percent** compared with tilled corn-soy, to rates that reflect the best available science for natural soil replacement, meaning a self-sustaining level of soil loss and replacement (Appendix 5 and Table 3).
- Taxpayers would achieve a **total annual savings of $124 million to $272 million from reduced surface water cleanup costs** in the 20 or 25 percent and 40 percent scenarios (Appendix 6 and Table 4, p. 10).
- Society would achieve **reductions in heat-trapping gas emissions (due to reductions in nitrogen fertilizer application in the diverse rotations) valued at $36 million to $72 million annually** and **carbon sequestration benefits valued at $74 million to $161 million annually** (Appendix 6 and Table 4).

Farmers Face Obstacles to Adopting Diverse Crop Rotation Systems

To recap, researchers at Iowa State University have demonstrated that diverse crop rotation systems offer a variety of benefits, and our economic analysis has shown that such systems could be feasibly scaled up over millions of acres of farmland in Iowa (and likely beyond), while maintaining farmers' profits and providing significant economic and environmental benefits to downstream communities, taxpayers, and society at large. So why are farmers not already adopting these systems in larger numbers? As business operators, often with slim profit margins, farmers face numerous barriers when it comes to adopting new or unfamiliar practices such as modified crop rotations. These include market and financial barriers, constraints regarding crop insurance and loans, and technical and information barriers.

MARKET BARRIERS

Midwestern farmers face several market barriers: markets for oats and other small grains today are not as well developed as markets for corn and soybeans, demand for these commodities is lower, and infrastructure such as seed suppliers and grain storage facilities are less ubiquitous. It is likely that new markets for these crops (and the infrastructure to serve them) will emerge to meet supply over time, but farmers may initially be daunted by the greater challenge of getting new crops into the hands of customers.

FINANCIAL BARRIERS

Adding new crops to their usual rotations may require farmers to make significant up-front investments—for example, in new equipment—and incur higher costs in the short term. Moreover, a majority of US farmers lease farmland from others; typical short-term leases do not allow for long-term planning or provide any incentives for improvements in soil health (The Nature Conservancy 2016). And high rent costs may discourage investments in innovation.

CROP INSURANCE AND CREDIT CONSTRAINTS

Until recently, provisions of federal crop insurance programs have discouraged diverse rotations by insuring just a few crops and encouraging farmers to plant them exclusively; farmers could lose benefits for acres not planted to those

David N. Sundberg/Iowa State University

Farmers wishing to add a new crop, such as oats, into a corn-soy rotation may need new equipment. Public policies should expand available funding to help farmers with such up-front costs.

TABLE 3. Soil Erosion before and after Conversion to Longer Rotations—across Iowa

	Base (tillage)	Corn-Soy-Oats (no till)	Corn-Soy-Oats-Alfalfa (no till)
Average Soil Erosion Rate (tons/acre)	4.76	0.54	0.59
Drop in Soil Erosion (tons/acre)		4.22	4.16
Percentage Decrease in Soil Erosion		88.69%	87.54%

Note: All numbers reported are soil delivery rates from the Daily Erosion Project Model for the period 2008–2015. See Appendix 5 for methodology used to generate these results.

SOURCE: IOWA STATE UNIVERSITY'S DAILY EROSION PROJECT MODEL (ISU 2016).

crops. In 2014, Congress created the Whole Farm Revenue Protection (WFRP) program, which enables diversified farmers to obtain coverage for all their crops and offers a premium subsidy of up to 80 percent when two or more crops are grown. But many county insurance agents lack training on how this program works, and anecdotal evidence suggests they often neglect to recommend the program to those who could benefit from it. And, even if farmers can obtain insurance coverage for new crops, lenders unfamiliar with the profitability potential of longer-rotation systems may be unwilling to make loans needed to help farmers adopt them.

TECHNICAL AND INFORMATION BARRIERS

For farmers to adopt new practices, they need evidence that these practices are feasible, can be implemented successfully at a local level, and will be beneficial to their bottom line. Publicly funded research programs are critical to providing this evidence, but research at the USDA and at public universities has focused too narrowly on a few commodity crops. In 2010, almost $212 million was spent researching just four commodity crops—corn, soybeans, wheat, and cotton (CRIS 2011)—while in 2016 the USDA devoted less than 15 percent of its competitive research funding to studies that considered agroecology, including diverse cropping systems (DeLonge, Miles, and Carlisle 2016). Farmers also need publicly funded technical guidance, yet the number of county-level agricultural extension agents tasked with advising them has declined in recent decades (Wang 2014).

TABLE 4. Annual Environmental Benefits from Longer Rotations—across Iowa

	Corn-Soy-Oats		Corn-Soy-Oats-Alfalfa	
	20% Feed Substitution	40% Feed Substitution	25% Feed Substitution	40% Feed Substitution
Acres Converted	5.75 million	11.35 million	5.25 million	7.16 million
CO_2 Equivalent Reductions[a]	0.17 ton/acre	0.17 ton/acre	0.20 ton/acre	0.20 ton/acre
Reduction in Emissions[b]	1.01 million tons	2.00 million tons	1.07 million tons	1.46 million tons
Dollar Value of Reduced CO_2 Emissions[c]	$36.51 million	$72.06 million	$38.65 million	$52.69 million
CO_2 Sequestered[d]	2.27 million metric tons	4.48 million metric tons	2.07 million metric tons	2.83 million metric tons
Dollar Value of Carbon Sequestered[e]	$81.75 million	$161.40 million	$74.51 million	$101.79 million
Savings in Surface Water Cleanup Costs[f]	$137.99 million	$272.37 million	$124.12 million	$169.55 million

a Results reported are from the nonlinear method. See Appendix 6 for methodology.
b Estimated as CO_2 equivalent reductions (ton/acre) × acres converted to corn-soy-oats/corn-soy-oats-alfalfa.
c Estimated as reduction in emissions × social cost of carbon ($36/ton) (EPA 2016).
d Though the rates of carbon sequestration from different agricultural practices are variable and still uncertain, we used data that suggest that carbon sequestration with conservation tillage could be an average of 0.50 metric ton/acre of CO_2-equivalent and with crop rotation could be an average of 0.29 metric ton/acre of CO_2-equivalent (The Nature Conservancy 2016). We used the average of these two numbers (0.39 metric ton/acre) of CO_2-equivalent. Thus, CO_2 sequestered is estimated as 0.39 × acres converted.
e Estimated as CO_2 sequestered × social cost of carbon ($36/ton).
f Calculated using Natural Resources Conservation Service estimates that for each ton of prevented soil erosion, surface water cleanup costs are reduced by $5.69 (2007 estimate was $4.93/ton; we updated to 2016 dollars) (NRCS 2009).

Public Policies Are Needed to Scale Up Diverse Rotation Systems

Federal farm policies—created and funded by Congress and implemented by the USDA—have played a major role in creating the dominant corn-and-soybean cropping system in the Midwest. Changes to these policies and investments are now needed to shift this system toward one that provides a wider range of benefits while maintaining yield and profits. By helping farmers overcome many of the barriers identified above, the following changes to existing federal programs and new programs would facilitate wider adoption of diverse crop rotations, which would in turn help shift markets over time and result in reduced erosion, reduced water pollution, and diminished global warming emissions.

Policymakers should:

- **Expand incentives and strengthen up-front financial support for farmers to shift to diverse rotations.** Changes to a variety of existing USDA programs can help farmers overcome financial barriers to entering new markets. Specific recommended changes include:
    - **Strengthening support in the Conservation Stewardship Program (CSP) for diverse crop rotations.** This federal program provides financial and technical assistance to farmers to implement practices that improve soil, water, and air; reduce energy use; and protect plant and animal life. Although the CSP currently provides some support to farmers if they implement resource-conserving crop rotations (RCCR)—the CSP term for a diverse crop rotation—the definition of RCCR used should be revised and clarified to ensure that it clearly requires a year-round mix of crops.
    - **Increasing support for rotations in the Environmental Quality Incentive Program (EQIP).** EQIP is a voluntary program that provides financial and technical assistance to farmers to plan and implement conservation practices that improve soil, water, plant, animal, air, and related natural resources. The program makes per-acre payments to farmers for implementing diverse crop rotations; however, the current payment schedule or payment rate is lower than two dollars per acre, which is inadequate considering the benefits provided by diverse crop rotations (NRCS 2015b). Because initial implementation costs of

diverse crop rotations are high and it may take a few years for benefits to accrue, payments to farmers should be increased to more appropriately incentivize them.

  - **Providing additional funding for USDA Farm Service Agency (FSA) loans.** In the 2014 farm bill, two programs were authorized, the FSA Direct and Guaranteed Operating Loans and FSA microloans, that can help cover some of the costs of implementing diverse crop rotations. Operating loans can be used to purchase seeds and equipment, among other items, and are typically used by more established farming operations. The microloan program is similar but designed to meet the needs of small, young, beginning, socially disadvantaged, and veteran farmers through a simplified loan application process. Microloans can cover expenses including initial startup costs, seeds, equipment, and minor farm improvements. Demand for both programs is high, and both require increased funding in the coming years to meet growing demand (NSAC 2015).

- **Strengthen federal crop insurance coverage for diversified farms through improved promotion of the WFRP program to farmers and better education of insurance agents and the public.** For decades, federal crop insurance was unavailable to farmers whose operations lay outside the boundaries of traditional commodity-driven monocultures. In 2014, Congress established the WFRP program, which extends coverage to diversified farmers. However, the USDA has not done enough to promote this new and unfamiliar program to farmers and insurance agents (Carlson 2017). Agents, in particular, need to better understand the provisions of the WFRP program so that they can accurately recommend the program to those who could benefit from it.
- **Increase government funding for research, technical assistance, and demonstration projects to help farmers understand the benefits of diverse rotations and the path to adopting them.** A greater practical understanding—on the part of farmers, extension service agents, and policymakers—of the benefits of optimal diversified farming systems in regions throughout the country will ultimately increase adoption rates. Additionally, more research needs to be devoted to how livestock producers can best incorporate different crops into their livestock feed. This requires:

  - **Fully funding the USDA's Agricultural Food and Research Initiative (AFRI) and increasing the program's focus on research related to agricultural diversification.** AFRI, a federal program that funds public agricultural research at institutions throughout the country, is tasked with fostering a better understanding of how to manage agricultural lands in order to improve the health of the farmland and surrounding environments. However, it is not fully funded. Congress should prioritize full funding for AFRI through appropriations and the farm bill. In addition, the program allocates a relatively small portion of its funding toward increasing the number of seed varieties available to farmers, and to ecosystems research. AFRI should increase its focus on research related to agricultural diversification.
  - **Funding long-term research that compares different farming systems.** Beyond AFRI, there is a need for the USDA to fund long-term research projects focusing on farming system comparisons—for example, comparing the two-crop system and the longer-rotation systems discussed in this report. The typical three- to five-year USDA competitive grant is too short to adequately capture the effects of diverse crop rotations on soil quality, water quality, or heat-trapping gas emissions, for example.
  - **Developing a farm pilot program to increase practical understanding of diverse crop rotations, their potential benefits for farmers, and how they can be implemented in various regions throughout the country.** Giving crop farmers tangible examples of successful diverse

[Federal farm policies—created and funded by Congress and implemented by the USDA—have played a major role in creating the dominant corn-and-soybean cropping system in the Midwest.]

crop rotations—and giving livestock farmers examples of how these crops can be incorporated as feed into their operations—are critical steps toward increasing the number of diverse crop rotations on the agricultural landscape. To this end, the USDA's Natural Resources Conservation Service, in partnership with state and local farmer organizations, should develop a multistate farm pilot program designed to provide farmers with this practical firsthand knowledge.

Conclusion

Agriculture can be productive and profitable without the damaging effects on the nation's soil, water, and air caused by today's widespread use of two-crop systems. Farmers can maintain high yields and sustained profits through an updated approach, one involving a more diverse set of crops and a modified strategy for protecting the soil. Supported by a set of policy changes that increase technical assistance and assist with up-front costs, US farmers can make the transition to a farming system that supports their livelihood, protects the natural resources on which it depends, and reduces the cleanup burden on taxpayers—all at once.

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Tim McCabe/USDA

The USDA's Natural Resources Conservation Service could increase the adoption rate of diverse crop rotation systems by developing a multi-state pilot project that provides farmers with firsthand knowledge of the benefits.

ENDNOTES

1 Includes the states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

2 Soil erosion costs both farmers and land owners. Farmers incur costs for fertilizer loss and for adding soil amendments (such as compost and manure) and/or for increasing the amount of fertilizer to maintain the yield before erosion. For land owners the value of farmland may decrease due to soil erosion. See Duffy 2012.

3 About 68 percent of farmers in Iowa use some kind of tillage practice (till or reduced till). Calculated using data from Tables 9 and 50 (Census of Agriculture 2012).

4 The corn and soybean plots were divided into halves and one of two weed management strategies—one using glyphosate-tolerant genetically engineered seeds and the other using non-genetically engineered seeds. Results were comparable. For details see Davis et al. 2012 and Hunt, Hill, and Liebman 2017. In the UCS analysis, we used the results of non-genetically engineered seeds.

5 Fall chisel plowing was used in all rotations after corn harvest to partially incorporate corn residue. Shallow fall disking was done to level plots after soybean harvest in the three-year and four-year rotations. Fall moldboard was performed in the three-year rotation to incorporate red clover and in the four-year rotation to incorporate the second-year alfalfa. Spring cultivation was carried out in all plots before planting in 2008–2010 and in the soybean plots in 2009 and 2010 (Davis et al. 2012).

6 All findings are from treatments subjected to tillage.

7 The calculations of net profitability assumed that there were costs for spreading and handling manure, but not for the material itself. Net profits would be affected if the cost of manure is included. The price of manure not produced on-farm depends on a number of factors, including supply and demand, and transportation and distribution costs.

8 The adoption of no-till techniques is almost always accompanied by an increase in herbicide use, since physical techniques for weed control are eliminated.

9 Calculated based on 2008–2015 data from Liebman 2016. See Appendix 1 for data.

10 A meta-analysis that looked at the impact of increasing ethanol production (therefore increasing corn demand) found that over the period of 2007–2014, corn prices increased by 2 to 3 percent for every 10 percent (1 billion gallon) increase in ethanol production (Condon, Klemick, and Wolverton 2015). Given the large demand for corn, a reverse argument can be made here—that is, reduction in corn production may not have a large impact on corn prices due to the global market for corn.

11 Average planted cropland acres from 2008 to 2015.

12 Note that the 25 percent most erodible counties would not necessarily contain the top 25 percent most erodible watershed districts. This is because watersheds cross county boundaries.

13 No-till surface cover from crop residue was the driving factor for these results.

14 For example, the current production for oats in Iowa is only 4.25 million bushels (2008–2015 average production). If all of the current available acres (24.6 million used for planting corn and soybeans) were converted to a three-year rotation, more than 8 million acres of oats would be planted, resulting in production that is more than 100 times the current production.

15 The results of this scenario of the model are not reported here. It is important to note that we are considering only Iowa production and demand in this model. While other states would meet some of the deficit in Iowa corn production, the initial increase in corn prices due to shortage in corn production in Iowa, one of the leading producers of corn in the Corn Belt, would motivate not only producers in other states but also producers in Iowa to respond to those high prices and revert to producing corn.

16 For oats, we considered only its feed use demand since the majority of oats currently produced is not food-grade quality. Over time, the quality of oats produced could be improved so that it can be used to meet the food demand for oats, thus increasing its overall market demand.

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Rotating Crops, Turning Profits

How Diversified Farming Systems Can Help Farmers While Protecting Soil and Preventing Pollution

Producing corn and soybeans in abundance has grown steadily less beneficial for US farmers. Despite record harvests in 2016, farm incomes are down and Corn Belt farmers are losing soil to erosion at unsustainable rates.

Replacing a fraction of current Midwest corn and soybean acres with a more diverse crop rotation system would produce higher yields and maintain farmers' profits while protecting their soil, cutting fertilizer and pesticide use and the associated costs, and reducing water pollution and global warming emissions. Our economic analysis of Iowa data shows that this more sustainable way of farming can be feasibly scaled up to as much as 40 percent of the state's farmland, with significant benefits to farmers, taxpayers, and rural communities. Federal policy changes are needed to support farmers in adoption of such systems, especially regarding up-front costs and farmers' need for practical, technical information.

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