Economic Impacts of Diversified Cropping Systems

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Introduction

1.1 Characteristics of the dominant US crop production system

Diversity of crops planted at the farm and regional levels has declined significantly in the last 50 years in the United States (US). (Porter et al., 2003, Liebman et al. 2003). Cereal grains and oilseeds now represent 59 percent of U.S. crop acreage while vegetables, fruits, and nuts account for only 2 percent (USDA, NASS, 2013). Monocultures and short cropping rotation sequences[1] with few crops has become the norm both in the United States as well as in other developed countries (Cook 2006, Brummer 1998). The average size of farms in the US has decreased with the number of commodities produced per farm declining from an average of five per farm in 1990 to just under two per farm in 2002 (Dimitri et al., 2002). This trend of specialized farming systems is very prominent in the Midwestern US Corn Belt[2]. In these states corn and soybean together constitutes 86% of the planted acreage. In contrast, oats occupy less than a 1 percent and hay only 6.85% of the planted acreage in the Corn Belt (USDA, NASS, 2013). This monoculture cropping system has led to greater dependence on synthetic pesticides and fertilizers and desertion of conservation practices to increase production (Hartwig et al., 2002). Absence of crop rotations has also increased vulnerability to pests, and therefore requires higher inputs of pesticides than most crops[3] (Pimentel and Lehman 1993). In addition, large scale adoption of genetically modified (GM) crops in the last 20 years has also resulted in greater reliance on fertilizers and pesticides[4]. Pesticide use has also increased significantly since the introduction of GM crops[5], which has coincided with the introduction and large increase of glyphosate making it one of the most heavily used pesticides in the US. Though insecticide use has declined the decrease is offset by the increase in herbicide use. Herbicide side use in the US increased by 108% in 2007 from 1995 levels, while insecticide use declined by 85% in 2007 compared to 1995 levels (Srinathsinghji, 2012). Heavy reliance on synthetic fertilizers and

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[1] Some factors that have led to the decline of longer crop rotation in the U.S include the advent of chemical fertilizers, in particular, nitrogen, synthetic pesticides, agriculture mechanization and the development of crop cultivars for a few select commodities (Bullock, 1992; Karlen et.al 1994).

[2] Iowa, Illinois, Indiana, Minnesota, Ohio and Wisconsin are the five states that make up the US Corn Belt.

[3] In the U.S., about 41% of all herbicides and 17% of all insecticides are applied to corn.

[4] In 2011 94% soybeans in the US was genetically engineered for herbicide tolerance (mainly glyphosate) while 72% of corn was genetically engineered for either herbicide tolerance or insect management or both (ERS, 2011).

[5] Due to the prevalence of a common GM trait which is tolerant to Monsanto's herbicide Roundup.

herbicides has had adverse impacts on the environment which include contamination of groundwater and surface waters, as well as on community health, ecosystems, and fisheries.

1.2 Consequences of conventional approaches to crop production- Impacts on environment and health

Industrialized agricultural techniques exert negative impact on the environment by polluting waterways, creating dead zones in the oceans, destroying biodiverse habitats, releasing toxins into food chains, endangering public health through disease outbreaks and pesticide exposures, while contributing to climate warming (Corrigan et. al., 2002, Tilman et al. 2002, Diaz and Rosenberg 2008, Marks et. al., 2010, Foley et al., 2011). Nitrous Oxide emissions (N_2O) are a leading consequence of industrialized agricultural production contributing to 5% of all U.S. greenhouse gas emissions from human activities. Agricultural soil management is the largest source of N_2O emissions in the U.S, accounting for about 74% of total US N_2O emissions in 2013. N_2O emissions are the result of addition of nitrogen to the soil through the use of synthetic fertilizers. More than 50% of the cropland in the US is rated as having high nitrogen balances which leads to greater susceptibility of soils to N_2O losses to the atmosphere[6] (EPA, 2013).

Fresh water pollution which is a consequence of nitrogen and phosphorus runoff from sewage seepage and agricultural runoff (from row crop agriculture) costs government agencies, drinking water facilities and individual Americans at least $4.3 billion each year[7](Kansas State University, 2008). Of this $4.3 billion, $44 million alone is needed for protecting aquatic species from nutrient pollution. Corn production needs large amounts of nitrogen fertilizer[8] a leading cause of ground and river water pollution and river water pollution responsible for creation of "dead zone" in the Gulf of Mexico. Large scale production of corn and soybeans and absence of crop rotations in the Midwest, has also increased annual average soil erosion annually from 2.7 tons/acre to 19.7tons/acre (Pimentel et al 995)[9].

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[6] CAST (2004) found that efficient use of nitrogen fertilizer could reduce emissions in the US by 30-40%.

[7] Various factors were taken into consideration when estimating the cost of water pollution. These include decrease in lakefront values, costs of treating drinking water and the revenue lost when fewer people participate in recreational activities such as fishing and boating.

[8] Average nitrogen application rates on US farmland vary between 120 kg/hectare and 550kg/hectare.

[9] Corn production causes more soil erosion than any other crop in the US

In addition, industrial agricultural techniques are inherently unsustainable in mining soils (Lal 2004, Tegtmeier and Duffy 2005, Montgomery 2007) and aquifers (Gordon et al., 2008) far more quickly than they can be replenished, and in their high use of fossil fuels (Lynch et al., 2011). High levels of aquifer contamination caused by nitrate are a cause for serious concern in many rural areas. Over 25% of the drinking water wells in the US have nitrate levels which exceed the recommended level of 45 parts per million safety standards (Conway and Petty, 1991). High nitrate levels also pose a threat to human health[10].

These numerous environmental and social externalities create a huge economic burden which is rarely paid by industrialized food producers. For example, pesticide use in the United States results causes up to $10 billion in damage to humans and ecosystems annually (Pimentel 2005).

The industrialized agriculture system has also affected consumers' access to healthy foods at an affordable price subsequently impacting their health.[11] More than 175,000 deaths in 2011 were due to some form of cardiovascular disease. More than 125000 deaths could be prevented and $17 billion in medical costs saved just by increasing consumption of fruits and vegetables to levels that meet dietary guidelines (O'Hara, 2013). Many people still lack access to diverse and healthy food, or ways to produce which results from a primarily a problem of distribution rather than production (IAAKSTD, 2009). Overproduction of food incentivizes agrifood companies to transform the excess food production into processed foods which is later marketed and distributed to customers in supersized portions (Nestle, 2003).

1.3 Influence of federal agricultural subsidy payments on commodity crop plantations

The federal subsidy program has also influenced the production of commodity crops[12]. The U.S. Department of Agriculture distributes between $10 billion and $30 billion in cash subsidies to farmers and owners of farmland each year. This amount depends on the market

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[10] Studies have shown that high nitrate consumption can cause metahemoglobinemia in children and gastric, bladder and esophageal cancer in adults.

[11] Crops such as corn have become a staple food in many processed food items such as sweetened breakfast cereals and soft drinks. These foods have been linked to the increase in the rate of type 2 diabetes which affects one in 12 million Americans. Between, 1985 and 2012 price of beverages sweetened with high fructose corn syrup dropped by 24% while the price of fruits and vegetables increased by 39% during the same period.

[12] While direct payments are traditionally decoupled from current production practices and considered less distortionary, significant amount of these payments are made to land owners whose land is no longer used for farming (Edwards, 2009)

prices for crops, the level of disaster payments, and other factors. More than 90 percent of agriculture subsidies go to farmers of five crops—wheat, corn, soybeans, rice, and cotton. Though 800,000 farmers and landowners are recipients of subsidies, but the payments are heavily skewed toward the largest producers. In addition to cash subsidies, the USDA also provides subsidized crop insurance, marketing support, and other services to farm businesses. The USDA also conducts extensive agricultural research and collects statistical data for the industry. The price tag for these indirect subsidies and services cost taxpayers is about $5 billion each year, and the estimated total farm support ranges from $15 billion to $35 billion annually (Edwards, 2009). Though the 2014 Farm Bill has eliminated direct subsidies to farmers it has expanded crop insurance coverage for farmers by $ 7 billion over a decade[13]. In addition new subsidies for rice and cotton growers have been introduced which come into effect when prices for these commodities drop.

1.4 Costs/downsides of the current system for farmers and farm communities

The industrialized agricultural system has had significant negative impact on small farmers and rural communities. With farm sizes getting larger, there has been a reduction in the total number of farms and decline in the role of farm workers. Despite the acreage remaining unchanged, the number of farms declined by 2 million in 2007. About 69% of the corn in the US is produced by large or very large farms[14](Srinathsinghji, 2013). There is little on-farm genetic diversity in the US agrosystem[15]. The large scale production of commodity crops has resulted in decline in the seed varieties available to small-scale, poor and organic farmers. Consequently, seed price have increased by 140% since 1994.With lack of experimentation by farmers there is an inherent risk of reduced resilience and ability to adapt to climate change and natural disasters (Heinemann et al, 2013).

2. Alternatives farming systems which rely on management of ecological relationships

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[13] The federally subsidized crop insurance program is administered by 18 companies which are paid 1.4 billion annually by the government to sell policies to farmers. These policies pay 62% of the farmer’s premium. Previously, the USDA would re-negotiate the insurance premium with these private insurance companies which sell insurance policies to farmers which would results in large cost savings to the government. However, this practice is banned in the current Farm Bill.

[14] The USDA defines large farms and very large farms as farms with sales over $250000 and $ 500000 respectively

[15] For example, 80-85% of corn in the 1980’s was the result of only one innovation, the T-cytoplasm.

Efforts to increase agriculture sustainability has resulted in the development use and management of agro-systems which use ecological processes to maintain soil productivity, improve crop yield and manage pest and weed population (Shennan, 2008, Anderson, 2007, Robertson and Swinton, 2005, Leibman and Gallandt, 1997). Alternative systems in contrast with conventional systems are known for using intensive management of ecological relationships rather than reliance on purchased fertilizers and pesticides to maintain productivity and profitability. Low–external-input (LEI) systems and organic farming systems are examples of alternate systems where soil, crop and pest conditions are closely observed to take maximum advantage of ecological interactions (Vereijken, 1992; Shea et al., 1998; Deming et al., 2007). Low-external input cropping systems offer various advantages which can improve soil structure (Raimbault and Vyn, 1991), reduce carbon and nitrogen losses (Dinnes et al., 2002, Drinkwater et al, 1998), add organic matter (Campbell and Zentner 1993), fix atmospheric nitrogen through legumes (Riedell et. Al, 2009), reduce the occurrence and intensity of crop diseases (Ghorbani et al., 2008,Tilman et al, 2002) reduce weed density (Anderson, 2005, Dyck and Leibman, 1994), increase soil microbial biomass(Deng et al., 2000, Bossio et al, 1998) and increase the efficiency of fossil-energy (Cruse et al., 2010). The main nutrients used in LEI systems are green and animal manures and other organic matter which also improve soil structure. Small amounts of herbicides in combination with cultivation and other cropping practices which expose weeds to various stress and mortality are also used to manage weeds (Leibman and Gallandt, 1997). Unlike organic systems LEI systems may use some manufactured fertilizers and pesticides and crop and livestock produced using LEI systems do not receive any price premiums (Liebman et. al, 2008). Nitrogen requirements in LEI systems are met with nitrogen released after decomposing legume residues and manure along with some synthetic fertilizer (Magdoff et al., 1997, Moriss et al., 1993 , Fox and Piekielek, 1988).

2.1 Rotational cropping systems- Diversification through crop rotation

Crop rotation is a method for diversifying the cropping system where different crop species are placed in the same field at different times. Rotational farming system have been used for many years for maintaining soil fertility and productivity, suppressing pests and can increase yields when significant quantities of fertilizers and pesticides are applied (Bennett et al., 2012, Karlen et al., 1994). They also encourage spatial diversity as different crops in a rotation system are planted on different part of the field in the same year. Diversification through rotation can be specifically beneficial for farms that integrate crop and livestock production (Davis et al., 2012). Alternative systems which use diverse crop rotations, integrate crop and livestock production and integrated pest management techniques can reduce negative environmental and health effects without reducing crop yields and in some cases may even increase crop yields and productivity of livestock management systems.

2.2 Impacts of Cropping system Diversification on yields, weed suppression, economic returns- Review of previous studies

A review of studies which tested the ability of diversified farming systems to produce high yields and maintain profitability by using smaller quantities of agrochemical inputs have shown mixed results. Some studies found that reduced fertilizer and pesticide use is possible while maintaining yields and profitability (Vereijken, 1986; Jordan and Hutcheon, 1995; Wijnands, 1997; Gallandt et al., 1998; Porteret al., 2003, Ponisio et al. 2014[16]). Others have found that yields and profitability of LEI systems are below conventional systems (Klonsky and Livingston, 1994; Munn et al., 1998; VanGesselet al., 2004). Therefore, to better understand the impact of diverse cropping systems, over a longer period a multi-year 9 hectare experiment was conducted at Iowa State University, Marsden Farm to test the hypothesis that cropping system diversification would eventually replace the need for synthetic inputs without sacrificing crop productivity and profitability[17].

2.3 Description of the field experiments carried out in the Marsden Study

The experiment was conducted at the Iowa State University Marsden Farm in Boone Co., Iowa from 2003-2011. The experiment site was planted with Oats in 2001 and plots were established in 2002. The plots followed a randomized complete block design with each phase of each rotation system present each year in four identical blocks. The size of the plot was 18m*85mm. Before the start of the experiment the site was planted with a corn/soybean rotation

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[16] The results of this study were based on a meta-analysis which showed that in organic systems adding diversification reduced the yield gap. This supports the benefits of diversified farming in achieving high yields on healthier farms, especially if healthier/organic farms received increased investments

[17] Initially, it was expected that inputs needs for diverse and less diverse systems would be similar but would even deviate as diverse systems matured. It was also expected that yields, weed suppression and economic performance of diverse and less diverse systems would be similar.

which received conventional fertilizer and herbicide inputs. The experiment compared 3 rotation systems: 2-year corn/soybean system, which is the typical cash grain farming system in the region, the 3 year corn-soybean –small grain/red clover system and the 4 year corn-soybean-small grain-alfalfa/alfalfa rotations represent diverse farming systems found in the region which often include swine or cattle. Oats was planted with red clover in the 3 year rotation and with alfalfa in the 4 year rotation during spring each year. Tillage operation[18] differed among rotation systems. Weed management strategies varied across rotations and management strategies in corn and soybean plots. Soil fertility management also differed among rotations. Synthetic fertilizer was applied in the two year rotation while composted cattle manure with reduced rates of synthetic fertilizer and herbicide was applied in the 3 year and 4 year rotation. The corn and soybean plots were divided into two halves and one of the two management strategies "GE (genetically engineered) and non GE was assigned to each plot. For corn, the GE management strategy used genetically engineered hybrid and the broadcast application of pre-emergence herbicides[19]. The non- GE strategy used non- genetically engineered hybrid combined with an application of post-emergence herbicides in a 38 band over the crop row. The GE strategy for soybean consisted of a genetically engineered variety with resistance to the herbicide glyphosate combined with post-emergence broadcast application of glyphosate. The soybean non-GE strategy used a non-genetically engineered seed and the application of a mixture of post-emergence herbicides in a 38-cm-band over the crop row[20] (Davis et al, 2012, Gomez et al, 2012Leibman et al, 2008).

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[18] Fall chisel plowing was used in all rotation after corn harvest to partially incorporate corn residue. Shallow fall disking was done to level plots after soybean harvest in the 3 year and 4 year rotation. Fall moldboard was performed in the 3 year rotation to incorporate red clover and in the 4 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.

[19] The GE corn was a stacked hybrid had genes to control European cornborer, Ostrinia nubilalis Hübner, and corn rootworms, Diabrotica spp

[20] For details of the corn hybrids and soybean varieties planted, and the pre and post-emergence herbicides applied see Leibman et.al, 2012

2.4 Key Findings from the Marsden Study

The data for the Marsden study consisted of data on yields, prices[21], variable costs[22] and net returns. Summary Statistics of the data are reported in Table 1. The average price for corn during this period was $5.2/dollars, for soybeans $11.5 dollars/bushels, for oats $2.97/bushel and for alfalfa $142.40/ton. Average yields for corn the period 2008 to 2012 were the highest in the 3 year rotation GE (C-SB-O) 197.52/bushel followed by the 3 year and 4 year non-GE rotations which were only slightly lower at 196.7/bushel.. The average soybean yield was the highest in the 4 year rotation at 55.7 bushels/acre. As with corn, the average yields for soybean in the more diverse 3 year and 4 year rotation were only slightly less. Average yield for oats was highest in the 4 year rotation at 101.64/bushel while the average alfalfa yield in the 4 year rotation was 4.35/ton.

The average net returns for corn for the period 2008-2012 were the highest in the 3 year non- GE rotation at $495.32/acre followed by the 4 year non-GE rotation at $473.16. Average net returns for soybean were the highest in the 3 year GE rotation at $206.21/acre. Average net returns or oats were negative in both the 3 year and 4 year rotation[23] while average net returns for alfalfa were $176.62/acre.

In summary, the Marsden study found that diversified cropping systems increased yields of corn and soybeans compared to the 2 year rotation. In addition, harvested mass such as grain straw and hay also increased. Weeds were suppressed effectively in all the systems and freshwater toxicity in the more diverse systems was lower than in conventional systems. Thus, the more diverse cropping systems by using small amounts synthetic and agrochemical inputs still match or exceed the performance of less diverse systems.

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[21] Price were average prices obtained from USDA.

[22] Variable costs include seeds, fertilizer manure, labor, machinery, seed, insurance& miscellaneous, and land.

[23] Net returns to Oats were positive in 2012 for the 3 year rotation. Net returns were also positive in 2011 and 2012 for the 4 year rotation.

2.5 Environmental Impacts

Many studies on nitrogen input in row-crop agriculture have found that there is a strong correlation between N_2O emissions and fertilizer N rate. (e.g., MacKenzie et al. 1998;Bouwman et al. 2002a; McSwiney and Robertson 2005; Mosier et al. 2006; Drury et al.2008; Dusenbury et al. 2008; Halvorson et al. 2008; Hoben et al. 2010, in review; Millar et al.2010, in review). All these studies found that increased addition of N to the soil led to increased N_2O emissions[24].

Using the Marsden study data on fertilizer application rate across the different rotations and the methodology described in Miller et al., 2010. (Appendix 2) we estimated the reduction in N_2O and equivalent emissions CO_2 emissions by moving from a 2 year C-S rotation to a 3 or 4 year C-S-O or C-S-O-A. Table 4 shows the fertilizer N application rate in the Marsden study for the 3 year and 4 year rotations. The fertilizer synthetic N application rate drops from 149 lbs/acre in the C-S rotation to 23 /lbs/acre in the C-S-O and the C-S-O- A rotation. The combined synthetic and organic fertilizer N application rate drops by 20% when we move from the 2 year C-S rotation to the more diverse 3 year or 4 year rotation.

Table 2 shows the reduction in N_2O emissions and CO_2 equivalent from a reduction in fertilizer N application rate a resulting of switching from a conventional C-S rotation system to a more diverse 3 year (C-S-O) or 4 year system (C-S-O-A). Using the linear method there is a reduction in N_2O emissions by 0.540 kg N_2O ha^{-1} year, in the non-linear approach, emissions reduce by 1.5 kg N_2O ha^{-1} yr. This is equivalent to reduction in CO_2 emissions of 0.158 mg CO_2 ha^{-1} year in the linear approach and by 1.78 mg N_2O ha^{-1}in the non-linear approach.

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[24] This result has been used as the basis for IPCC (2006) greenhouse gas inventory calculations.

Table 1: Summary Statistics of the Marsden Study Data from 2008-2012

	Rotation	**Yield** bushel/acre	**Price** $/bushel	**Net Returns M**[1] $/acre
Corn-GE	2 year	192.18	5.21	323.93
Corn-GE	3 year	197.52	5.21	437.81
Corn-GE	4 year	196.46	5.21	410.49
Corn-Non-GE	2 year	185.96	5.21	356.70
Corn-Non-GE	3 year	196.69	5.21	495.32
Corn-Non-GE	4 year	196.68	5.21	473.16
Soybean-GE	2 year	50.18	11.55	110.67
Soybean-GE	3 year	55.74	11.55	206.21
Soybean-GE	4 year	57.24	11.55	201.09
Soybean-Non-GE	2 year	42.82	11.55	23.41
Soybean-Non-GE	3 year	53.1	11.55	172.96
Soybean-Non-GE	4 year	54.74	11.55	169.52
Oats	3 year	95.66[2]	2.97	-17.119[3]
Oats	4 year	101.64	2.97	-20.21[4]
Alfalfa	4 year	4.35[5]	142.40[6]	176.62

[1] Net returns to management which includes land and labor cost.

[2] Yield is for grain only

[3] These are average net returns from 2008-2012. Net returns to Oats become positive in 2012 for the 3 year rotation.

[4] These are average net returns from 2008-2012. Net returns were positive in 2011 and 2012 for the 4 year rotation.

[5] Alfalfa yields are expressed as ton/acre

[6] Alfalfa price is $/ton

Table 2: Mean Fertilizer (Synthetic and Organic) Use 2008-2011

Rotation	**N Fertilizer** **Lbs N acre^{-1} yr^{-1}**	**Manure N** **Lbs N acre^{-1} yr^{-1}**
2 year		
Corn pre/GE	149	
Corn post/non GE	149	
Soybean GE[1]		
Soybean Non GE		
Rotation Average (GE)	74.5	
Rotation Average (Non-GE)	74.5	
3 Year		
Corn pre/GE	22.98	95.95
Corn post/non GE	22.98	95.95
Soybean GE	0	
Soybean Non GE	0	
Oat/Red Clover	0	
Rotation Average (GE)	7.66	31.75
Rotation Average (Non-GE)	7.66	31.75
4 Year		
Corn pre/GE	22.98	95.95
Corn post/non GE	22.98	95.97
Soybean GE	0	0
Soybean Non GE	0	0
Oats/Alfalfa	0	0
Alfalfa	0	0
Rotation Average (GE)	7.66	31.75
Rotation Average (Non-GE)	7.66	31.75

[1] The N application rate for soybean is very small 0.5kg/ha-^{1}/yr^{-1}, therefore is not shown.

Table 3: Annual Reduction in N_2O emissions (Kg N_2O ha^{-1} yr) and carbon dioxide equivalents (Mg N_2O ha^{-1} yr)

	N_2O Reductions Kg N_2O ha^{-1} yr	**CO_2 Reductions Mg N_2O ha^{-1} yr**
Linear	0.530	0.158
Non-Linear	1.494	1.78

3 Methodology

As seen in the previous section, the long-term Marsden Farm study has shown that diversified farming systems can be profitable on a small scale. We use data from that experiment to analyze the feasibility of the diversified farming system could if the practices employed at Marsden were adopted on a larger scale in state of Iowa. Converting the entire cropland and in Iowa into either 3 year or 4 year rotation would results in significant reduction in corn and soybean acreage and production and increase in corn and soybean price. At the same time, adopting a diverse rotation system would result in increasing the acreage of oats and alfalfa and an influx of additional oats and alfalfa in the market and lower prices for these crops. Thus the system would revert back to the current system with high prices of corn and soybean encouraging production of these crops. While some of the increased production can be absorbed by increased demand[25] absorbing the entire acreage is challenging. Therefore, we constructed a scenario which looked at evaluating the impact of adopting diverse crop rotation on a portion of the cropland in Iowa. Thus, we assumed that 50% of the cropland in Iowa (12.2 million acres) will be planted under a C-S-O rotation. Thus, 4 million acres of each crop are planted under a diverse rotation system (3 year) and the remaining cropland will be planted under prevailing agricultural practices[26]. In the 4 year rotation, we assume that one-third of the cropland (8 million) acres are planted in a 4 year rotation while the remaining acres are devoted to prevailing agricultural practices. We use a non –linear optimization (quadratic) model with endogenous price and quantity (Appendix 1) that produces a market clearing equilibrium by satisfying two constraints- total land availability and the crop rotation constraint- minimum acreage that must be planted for each crop to meet the

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[25] In our simple model there is no iterative process where demand from other markets such as livestock and dairy responds to the increased supply.

[26] The dominant crops planted in Iowa are corn and soybean. The number of acres of corn and soybean planted on the remaining acres is based on the proportion of corn acreage and proportion of soybean acreage planted from 2008- 2012. The yields used are average corn and soybean yields for the period 2008-2012 from NASS,USDA.

rotation requirement. In addition to the land availability and rotation constraints, we have a balance constraint that must be satisfied, that is quantity demanded is equal to quantity supplied (to determine equilibrium price).

Land is divided equally, into 3 parts and 4 parts based on rotation. We estimate a separate model for each rotation. In both models, there was a restriction on the total available land which was set to 12.2 million acres, in rotation 3 and 8 million acres in rotation 4. The rotation restriction is based on the requirement that one crop must be alternated with the other and is set as a strict equality constraint, that is acreage of one crop must be equal to the other.

We also assume that in the 3 year rotation because there will be a significant increase in production in the oats and decrease in the production of corn and soybeans a portion of the feed demand for corn and soybean will be replaced by oats[27]. Oats are assumed to substitute for 20% of the corn feed demand in the 3 year rotation[28]. In the 4 year rotation, it is assumed that oats substitute for 10% and alfalfa substitute for 10% of the corn feed demand.

4 Results

The results of scenario 3 are reported in table 4. The optimal acreage for the different crops, quantity produced in bushels/ton, base prices (initial) and new the equilibrium prices, that is prices at which demand is equal to supply are shown in the table. With reduced acreage converted to diverse rotation system (either 3 or 4 year rotation), price impacts are nominal. By converting 12.2 million acres into a 3 year rotation, 4.06 million acres will be allocated to corn production. Because the corn yields are higher using complex rotation system, there is increased production. Therefore, the remaining demand for corn can be met (using conventional methods) by allocating only 5.8 million acres. Thus, total acreage allocated to corn is around 9.87 million

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[27] It is expected that with influx of oats in the market at a lower price than livestock producers will adjust their feed rations so that some of the corn in their in the feed ration can be substituted with oats thus increasing the demand for oats and reducing the demand for corn. A more comprehensive model where dairy and livestock markets are modelled is needed to get at the exact impact. In our simple model there is no iterative process where demand from other markets such as livestock and dairy responds to the increased supply.

[28] This is based on a 2002 Study by Honeyman et.al which looked performance of market hogs in deep-bedded hopped barns when an addition of 20% and 40% oats were added to their diets. The study found no difference in feed efficiency, feed intake, daily weight gain and other factors with the addition of either the 20% or the 40% oats in hog diets. Please see Honeyman et al, 2002 for details.

acres down from the average of 13 million acres. Similarly, in the 4 year rotation total acreage allocated to corn is 10.25 million acres.

Table 4: Results

	C-S-O[1]			C-S-O/A-A[2]			
	C[3]	**S[4]**	**O[5]**	**C[6]**	**S**	**O[8]**	**A[7]**
Acreage[8]	4.07	4.07	4.07	2	2	2	2
Total Acreage[9]	9.87	9.1		10.25	9.17		
Production[9]	799.91	215.9	389.18	393.4	109.4	203.28	328.2
Initial Price[10]	5.2	11.5	3.8	5.2	11.5	3.8	3.77
Equilibrium Price[11]	5.2	11.5	3.8	5.2	11.5	3.8	3.76

Note: This was estimated using average yields for the different crops. Using higher/lower yields decreases/increases the price. The results reported are for non-GE corn and soybean crops. The difference between GE and non-GE data is in the yield /acre and the variable cost per acre differ slightly in the GE and non- GE versions

[1, 2] Corn-Soybean-Oats, Corn-Soybean-Oats/Alfalfa-Alfalfa respectively

[8] Millions of acres

[9] Sum of cropland under diverse rotation and proportion of remaining cropland allocated to corn/ soybean production

[11] Millions of Bushels

[10] Average prices for the period 2008-2012 with the exception of oats where 2011 price is used.

[11] Calculated taking into consideration production through 3 year/4 year rotation and Corn and soybean production using conventional farming.

5. Conclusions and Recommendations

Alternative agriculture systems that use diverse cropping patterns, mixed crop-livestock production and integrated pest management can reduce adverse environmental and health effects without reducing yields and productivity. This was demonstrated by a recent study conducted at Iowa State University, Marsden Farm, Boone County, Iowa which compared yield, weed suppression and profitability of low-external-input cropping systems to conventional cropping systems. The study showed that more complex rotations which substitute other crops for some of the corn and soy on a farm can have a variety of benefits, from reduced pesticide use to increased scale. We use data from that experiment to we analyze the economic feasibility if the practices employed at Marsden were adopted on a larger scale in the Midwest. We found that adopting the Marsden farm practices over the over half of the cropland (12.2 million) into a 3 year rotation or one-third (8 million acres) of the cropland into 4 year rotations could work without having an impact on prices assuming some of the increased production of oats and alfalfa is substituted for corn in feed rations. This would have the benefit of reducing total corn acreage[29] because of higher yields for corn in the Marsden data (due to the benefit of rotations) and substitution of some of the corn with oats. In addition we also found that there are significant reductions in N_2O emissions by moving to a 3 year or 4 year rotation system.

A diversified farming system can be profitable and have significant environmental benefits. However, there is often absence of understanding/ appreciation among farmers for system-level performance, i.e., performance of the individual components of a production system is valued more than overall system performance[30] Also, there are lack of incentives to adopt production systems that are diverse and environmentally beneficial. Policy incentives to increase widespread adoption of sustainable farming systems can go a long way. We propose the following recommendations:

- Ensure farmers receiving federal subsidies employ at least a minimum level of conservation and limit their use of environmentally destructive practices.
- One of the barriers to adoption of the sustainable farm systems is the lack of publicly funded research to improve and expand modern, sustainable food and farm systems**.** This research should seek to:
- Increase understanding of the ecosystems that support farming and the impacts of various management systems, practices, and technologies;
- Develop and refine innovative systems for sustainable, organic, and diversified food production, and ease farmers' transitions to them;

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[29] By converting 12.2 million acres into a 3 year rotation, 4.06 million acres will be allocated to corn production. Because the corn yields are higher using complex rotation system, there is increased production and also some of the corn demand is substituted for oats.. Therefore, the remaining demand for corn can be met (using conventional methods) by allocating only 5.8 million acres. Thus, total acreage allocated to corn is around 10.million acres down from the average of 13 million acres.

[30] For example, while it may seem more profitable to plant more acreage of corn over small grains such as oats or alfalfa, it is the inclusion of such crops which in turn increase the yields of corn and the performance of the system.

- Foster the expansion of local and regional food systems, and better document their economic benefits;
- Increase the diversity of our agriculture system and promote resilience in the face of environmental challenges, through public crop and livestock breeding programs and other efforts.

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Appendix 1: Optimization model

Quadratic Model:

The objective function of the model is:

$$\max\ Z_i = \sum_j^n \left(\alpha_j - \tfrac{1}{2}\beta_j\ Q_j\ \right) Q_j\ - \sum_j^n C\left(S_j\right) \qquad (1)$$

where

$$i = 3\ or\ 4\ \ year\ rotation\ ,$$
$$j = 3\ for\ 3\ year\ rotation\ and\ 4\ for\ 4\ yr\ rotation$$

α_J is the intercept[31]

β_j = Slope of the variable[32]

Q_j is the quantity for crop j

$C(S_j)$ are the costs

where $S_j\ = y_j X_j$ and $y_j\ is$ yield/acre for crop j and X_j is the total acres planted for crop j

subject to

$0 \geq$ Land $\leq$ 12.2 (3 year rotation) (2)

$0 >$ Land ≤ 8 (4 year rotation) (3)

$$X_{corn}\ = X_{soybean}\ =\ X_{oats} \quad \text{(3 year rotation)} \qquad (4)$$

$$X_{corn}\ = X_{soybean}\ =\ X_{oats}\ =\ X_{alfalfa} \ \text{(4 year rotation)} \qquad (5)$$

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[31] Own price feed demand elasticities for corn, soybean, oats and hay are used to calculate the intercept and slope. These are obtained from the FAPRI –Missouri (FAPRI-MU, 2011). The intercept is calculated as Initial price – Slope*Initial Quantity.

[32] The slope is calculated as elasticity*Initial Price/Initial Quantity. Quantity data is obtained NASS,USDA

$Q_j - S_j \leq 0,$ all j $[\pi_j]$ (6)

and

$Q_j, S_j > 0$ (7)

Equations (2) and (3) are the land constraints which restrict the total available land to 12.2 million acres in rotation 3 and 8 million acres in rotation 4. Equations (4) and (5) are the rotation constraints so that equal acres of the different crops are planted in each rotation. Equation (6) is the balance constraint created for each crop in each rotation to ensure that in equilibrium supply= demand (from partial equilibrium modelling approach). The shadow price of the balance equation is the equilibrium price. The last equation (7) is the negativity constraint.

The demand curves are exogenously specified. Restrictions on total available land and how much land should be used to produce each crop are dependent on the rotation requirement and play an important role in determining the supply curve. Cross price effects are generated exogenously rather than being included explicitly in the analysis (Hazel and Norton, 1986)

Appendix 2: Calculation of N_2O

The methodology used to calculate the annual direct emission reduction of N_2O from the corn component of (C-S-O) rotation and corn amount of corn-soybean-oats-alfalfa-alfalfa (C-S-O-A) rotation due to reduction in fertilizer N rate is described below. This reduction is a result of switching from 2 year corn-soybean rotation to a more diverse 3 year rotation or a 4 year rotation.

Emission reduction of N_2O due to reduction in annual fertilizer N rate is calculated as:

$N_2O_R = N_2O_{+N(B)} - N_2O_{+N(A)}$ (1)

Where:

N_2O_R = Reduction in emissions due to fertilizer N rate reduction, kg C_2Oe $ha^{-1}yr^{-1}$

$N_2O_{+N(B)}$ = Direct c emissions following N fertilizer input before fertilizer N rate reduction, kg C_2Oe $ha^{-1}yr^{-1}$

$N_2O_{+N(A)}$ = Direct emissions following N fertilizer input after fertilizer N rate reduction, kg C_2Oe $ha^{-1}yr^{-1}$

Following Miller et. al, 2010, we use two approaches- linear and non-linear approach to estimate N_2O emissions. Equation 2 below is used to estimate emissions from both the approaches.

$$N_2O_{+N(B/A)} = [(F_{SN}+F_{ON})_{(B/A)} * EF_N) + N_2O_{0N(B/A)}] * N_2O_{MW} * N_2O_{GWP} \qquad (2)$$

where

$N_2O_{+N(B/A)}$ = Direct N_2O emissions following N fertilizer input, kg C_2Oe $ha^{-1}yr^{-}1$

$N_2O_{0N(B/A)}$[33] = Direct N_2O emissions following zero (0) fertilizer N input, kg N_2O –N $a^{-1}yr^{-}1$

$F_{SN\ (B/A)}$ = Mass of N applied from synthetic fertilizer, kg N $ha^{-1}yr^{-}1$

$F_{ON\ (B/A)}$ = Mass of N applied from organic fertilizer, kg N $ha^{-1}yr^{-}1$

EF_n = Emission factor for N_2O emissions from N inputs, kg N_2O –N (kg N input)$^{-1}$
(n=1 and 2 for linear and non-linear approaches, respectively)

N_2O_{MW} = Ratio of molecular weight of N_2O to N, kg N_2O (kg N)$^{-1}$

N_2O_{GWP}[34] = Global Warming Potential for N_2O, kg C_2Oe (kg N_2O)$^{-1}$

EF_1: The IPCC Tier 1 default emission factor (EF1) has a value of 0.01 or 1.0% (IPCC 2006), and is insensitive to fertilizer N rate. The emission factor of 1.0% represents an annual direct loss of N_2O –N of 1.0 kg N ha^{-1} for every 100 kg N ha^{-1} of fertilizer N applied in that same year.

EF_2: The value of the regional Tier 2 emission factor (EF_2) determined from the N fertility gradient on-farm field sites in Michigan (Hoben et al. 2009) is sensitive to N rate and can be expressed as:

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[33] To account for background anthropogenic N_2O emissions (Bouwman 1996), N_2O emissions from a zero fertilizer N rate control (N_2O_{0N}) scenario are included. The regional value for these background emissions as determined from the N gradient sites in Michigan is 1.47 kg N_2O –N $ha^{-1}yr^{-1}$ (Hoben et al. 2009). When we compare N_2O emissions between linear and non-linear method, this value for N_2O emissions from the zero fertilizer rate control is used in both methods.

[34] The GWP value of 298 for N_2O which is used. This is the 100-year value used in the most recent IPCC Fourth Assessment Report (Forster et al. 2007), and is the direct GWP for one molecule of N_2O on a mass basis for a 100 year time horizon, relative to one molecule of CO_2, which is given a value of 1 by convention. This means that a molecule of contemporary N_2O released to the atmosphere will have 298 times the radiative impact of a molecule of CO_2 released at the same time. Thus, an agronomic activity such as reduction in fertilizer N rate that reduces N_2O emissions by 1 kg ha−1 is equivalent to an activity that sequesters 298 kg ha−1 CO_2 as soil C (Robertson and Grace 2004).

$EF_{2} = 0.012 * \exp [0.00475 * (F_{SN}+F_{ON})]$

The two approaches differ in terms of emission factor used. The linear approach uses the emission factor 1 while the non-linear approach uses EF_2 The subscripts (B) stands for the scenario before the fertilizer N rate reduction while subscript (A) is for the scenario after the reduction. Variables which do not have this subscript do not change for the two scenarios:

Calculation of N_2O emissions

Linear : N_2O-N[35] = 1.47 + (0.01* Fertilizer N rate)
Non-linear: : N_2O-N = 1.47 + [(exp*0.0082*Fertilizer rate)]

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[35] The conversion of N_2O–N (the mass of the nitrogen component of the nitrous oxide molecule) to N_2O (N_2OMW) is calculated as the product of the ratio of the molecular weight of N_2O to the atomic weight of the two N atoms in the N2O molecule, i.e., $N_2O = N_2O – N×44/28$.