Rotating Crops, Turning Profits

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

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Appendix 1: Fertilizer Use in the Iowa State University Study

TABLE A1.1. Mean Fertilizer (Synthetic and Organic) Use, 2008–2015

Rotation	N Fertilizer Lb. N Acre^{-1} Yr^{-1}	Manure N Lb. N Acre^{-1} Yr^{-1}
Two-year		
Corn	154.71	
Soybean[a]		
Rotation average	77.35	
Three-year		
Corn	27.11	109.67
Soybean	0	
Rotation average	9.04	36.56
Four-year		
Corn	23.99	109.67
Soybean	0	0
Rotation average	5.99	27.42

Note: All results reported are for non-genetically engineered crops.

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

SOURCE: LIEBMAN 2016

Appendix 2: Optimization Model

The long-term study at Iowa State University found that longer rotation systems are similar in profitability to the shorter, conventional system, and do a better job at protecting environmental quality. Because these systems provide additional soil health benefits without compromising profitability, we hypothesized that farmers would be inclined to adopt longer rotation systems particularly if supported by policy initiatives. However, if a large number of farmers adopted longer rotations, it would result in a reduction of corn/soybean and a significant increase in production of oats and alfalfa (significantly more than the current market demand), thereby impacting prices. Therefore, we analyzed the extent to which these systems could be scaled up while maintaining a market equilibrium. We considered two cases: (1) scaling up longer rotation systems on the most erosive croplands in Iowa, and (2) scaling up longer rotation systems across the entire state of Iowa. We used a non-linear optimization (quadratic) model with endogenous price, that is, one that considers the impact of changing demand and supply on prices by satisfying two constraints: 1) total land availability, and 2) the crop rotation constraint (minimum acreage that must be planted for each crop to meet the rotation requirement). A third (balance) constraint was added that looks at the impact of changing supply and demand to determine the market price.

The model took the following form:

$$\max Z = \sum_{j}^{n} \left(\alpha_J - \tfrac{1}{2}\beta_j\, Q_j\right) Q_j - \sum_{j}^{n} C\left(S_j\right) \qquad (1)$$

where

α_J is the intercept[1]
β_j = slope of the variable[2]
Q_j is the quantity for crop j
$C\left(S_j\right)$ are the costs

where

$S_j = y_j X_j$ and y_j[3] is yield/acre for crop j and X_j is the total acres planted for crop j

subject to

$0 \geq \text{land} \leq \text{total available land} \qquad (2)$
$X_{corn} = X_{soybean} = X_{oats}$ (three-year rotation) (3)
$X_{corn} = X_{soybean} = X_{oats} = X_{alfalfa}$ (four-year rotation) (4)

such that

$Q_j - S_j \leq 0, \quad \text{all j } \left[\pi_j\right] \qquad (5)$

and

$Q_j, S_j > 0 \qquad (6)$

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

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[1] Own price feed demand elasticities for corn, soybean, oats and hay are used to calculate the intercept and slope. These are obtained from the Food and Agricultural Policy Research Institute–Missouri (FAPRI 2011). The intercept is calculated as initial price – slope * initial quantity.

[2] The slope is calculated as elasticity * initial price / initial quantity. Quantity data were obtained from the National Agricultural Statistics Service (NASS 2016).

[3] In case 2, we used the percentage change in yields from the Iowa State experiment after switching from C-S rotation to a C-S-O/C-S-O-A rotation. However, it is unclear whether yields would increase at the same percentage level on erodible soils as they did on the flat soil of the Iowa State study after adopting a C-S-O or C-S-O-A rotation. Therefore, we made a conservative estimate that yields will increase at half the rate as the yields in the Iowa State study in case 1.

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 were generated exogenously rather than being included in the analysis (Hazel and Norton 1986).

Land was divided equally into three parts for the three-year rotation and four parts for the four-year rotation. We estimated separate models for the C-S-O (corn-soybean-oats) and C-S-O-A (corn-soybean-oats-alfalfa) systems in the two cases outlined above. Our model is a hypothetical case; therefore, we showed the feasibility of adopting both the C-S-O and C-S-O-A systems. In reality, farmers have limitations other than the amount of land available, such as the length of the lease as well as availability of labor, and their choice to adopt one system over the other may be influenced by these other constraints. For example, the humid weather in Iowa limits the time available to complete a harvest to one to two weeks (as opposed to two to three months for corn), which may pose a challenge to growing alfalfa on a large scale, encouraging farmers to adopt a three-year rotation.

TABLE A2.1. Impacts of Conversion of Corn Acreage in the Top 25 Erodible Counties in Iowa to C-S-O/C-S-O-A Rotation.

	Three-Year 10% Feed Substitution			**Four-Year 10% Feed Substitution**			
	Corn	**Soybean**	**Oats**	**Corn**	**Soybean**	**Oats**	**Alfalfa**
Acreage (millions)	1.21	1.21	1.21	0.91	0.91	0.91	0.91
Total acreage (millions)[a]	12.73	9.48	1.21	12.92	9.46	0.91	0.91
Production (millions)[b]	209.21	63.52	87.50	158.13	48.75	71.84	3.22
Initial price[c]	$4.72	$11.20	$3.17	$4.72	$11.20	$4.72	$148.80
Equilibrium price[d]	$4.72	$11.20	$3.17	$4.72	$11.20	$4.72	$148.80

Note: This was estimated using average yields for the different crops. We used the percentage change in yields from the ISU experiment after switching from C-S rotation to a C-S-O/C-S-O-A rotation. However, it is unclear whether yields would increase at the same percentage level on erodible soils as they did on the flat soil of the Iowa State study after adopting a C-S-O or C-S-O-A rotation. Therefore, we made a conservative estimate that yields will increase at approximately half the rate as the yields on the Iowa State plot. Using higher/lower yields decreases/increases the acreage that could be converted. The results reported are for non-genetically engineered corn and soybean crops. The difference between data from genetically engineered and non-genetically engineered crops is in the yield per acre and the variable cost per acre (due to rotation diversity and manure addition).

[a] Sum of cropland planted under C-S-O/C-S-O-A rotation and proportion of remaining cropland allocated to corn/soybean production

[b] Millions bushels for corn, soybean, and oats and millions metric tons for alfalfa. Calculated taking into consideration production in the C-S-O/C-S-O-A rotation.

[c] Average prices for the period 2008–2015. Prices are $/bushel for corn, soybean, and oats, and $/ton for alfalfa.

[d] Price at which supply and demand are equal. Calculated taking into consideration production in the C-S-O/C-S-O-A rotation and corn and soybean production using dominant (C-S) system.

TABLE A2.2. Impacts of Conversion of Corn Acreage Across Iowa to C-S-O Rotation

	Three-Year 20% Feed Substitution			Three-Year 40% Feed Substitution		
	Corn	**Soybean**	**Oats**	**Corn**	**Soybean**	**Oats**
Acreage (millions)	1.92	1.92	1.92	3.78	3.78	3.78
Total acreage[a] (millions)	12.21	9.35	1.92	11.19	9.16	3.78
Production[b] (million bushels)	333.84	105.01	169.43	659.29	207.39	334.60
Initial price[c] ($/bushel)	$4.72	$11.20	$3.17	$4.72	$11.20	$3.17
Equilibrium price[d] ($/bushel)	$4.72	$11.20	$3.17	$4.72	$11.20	$3.17

Note: This was estimated using the percentage change in average yields for the different crops after conversion from C-S to C-S-O rotation from the Iowa State study. The percentage change was applied to average yields of the crops (2008–2015) using data from the National Agricultural Statistics Service (NASS 2016). Modeling higher/lower yields decreases/increases the acreage that could be converted. The results reported are for non-genetically engineered corn and soybean crops. The difference between data from genetically engineered and non-genetically engineered crops is in the yield per acre and the variable cost per acre (due to rotation diversity and manure addition).

[a] Sum of cropland planted under diverse rotation (C-S-O) and proportion of remaining cropland allocated to corn/soybean production
[b] Production reported for C-S-O rotation
[c] Average prices for the period 2008–2015
[d] Price at which supply and demand are equal. Calculated taking into consideration production in the C-S-O rotation and corn and soybean production using dominant (C-S) system.

TABLE A2.3. Impact of Conversion of Corn Acreage Across Iowa to C-S-O-A Rotation

	Four-Year 25% Feed Substitution				Four-Year 40% Feed Substitution			
	Corn	Soybeans	Oats	Alfalfa	Corn	Soybeans	Oats	Alfalfa
Acreage (millions)	1.31	1.31	1.31	1.31	1.79	1.79	1.79	1.79
Total acreage (millions)[a]	11.92	9.31	1.37	1.31	11.22	9.22	1.79	1.88
Production (millions)[b]	231.63	76.38	123.94	5.24	316.63	104.42	169.43	7.16
Initial price[c]	$4.72	$11.20	$3.17	$148.80	$4.72	$11.20	$4.72	$148.80
Equilibrium price[d]	$4.72	$11.20	$3.17	$148.80	$4.72	$11.20	$4.72	$148.80

Note: This was estimated using percent change in average yields for the different crops after conversion from C-S to C-S-O-A rotation from the Marsden farm study. The percent change was applied to average yields of the crops (2008-2015) using NASS, USDA data. Using higher/lower yields decreases/increases the acreage that could be converted. 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.

[a] Sum of cropland planted under diverse rotation (C-S-O/C-S-O-A) and proportion of remaining cropland allocated to corn/ soybean production
[b] Millions of bushels for corn, soybean, oats, and million metric tons for alfalfa
[c] Average prices for the period 2008–2015. $/bushel for corn, soybean, and oats, and $/ton for alfalfa
[d] Price at which supply and demand are equal. Calculated taking into consideration production in the C-S-O-A rotation and corn and soybean production using dominant (C-S) system.

Appendix 3: Adoption of Dried Distiller Grains in Livestock Diets

As ethanol production increased significantly from 2000 to 2008, so did the quantity of dried distiller grains (DDGS), a by-product of ethanol production available in the market. DDGS production more than tripled from just 10.4 million metric tons in 2005/2006 to 34.1 million metric tons in 2010/2011. As stated in a recent Food and Agriculture Organization report, the increased adoption of DDG in livestock diets was a result of the question "what are we going to do with the 'mountains' of DDGS produced by the exponential growth of the ethanol industry?" (Shurson, Tilstra, and Kerr 2012). The concern over the amount of DDGS being produced resulted in corn grower associations from several states as well as livestock and feed organizations allocating significant funding to several universities to conduct research on animal nutrition, particularly with regard to using DDGS as a feed. Thus, along with the growth of the ethanol industry there was a large increase in research conducted at both universities and feed industry companies on outlining the benefits and drawbacks of incorporating DDGS in livestock, poultry, and aquaculture diets.

Published results from several key studies on dairy (Schingoethe, et al. 2009), beef (Klopfenstein, Erickson, and Bremer 2008), and swine (Stein and Shurson 2009) had a large impact on the acceptance and adoption of DDGS by the feed and livestock industries. Similarly, published results from initial studies on the use of DDGS on poultry contributed significantly towards the increased adoption of DDGS in poultry feeds worldwide (Batal and Dale 2006; Lumpkins and Batal 2005; Lumpkins, Batal, and Dale 2005; Lumpkins, Batal, and Dale 2004; Batal and Dale 2003). The extensive research led to the establishment of maximum dietary inclusion rates as follows: lactating dairy cows, 30 percent; beef feedlot cattle, 40 percent; swine, 30 percent all phases and up to 50 percent in gestation; and poultry, 5 percent. In addition, there was extensive media attention dedicated to the growing ethanol industry as well as the creation of university and industry web sites (e.g., www.ddgs.umn.edu) pertaining to the use of DDGS in animal diets, which played a major role in communicating information on DDGS to end users across the world.

Consequently, there was a dramatic increase in the market for DDGS and, for the first time, a significant market was created for DDGS in the US swine and poultry industries. In addition, extensive attention was devoted by the US grains industries toward the development of export markets for DDGS worldwide. This led to a significant growth in US exports of DDGS, which increased from 1.2 million metric tons in 2005/2006 to 8.7 million metric tons in 2010/2011. Thus, a market for DDGS was created.

Additionally, many nutritional rules of use—for example, with regard to dairy cattle—had been developed at a time when corn was a cheap and easily available feed ingredient. However, the abundant use of corn in dairy rations is not an absolute requirement, both from a nutritional and an economic perspective (St. Pierre and Knapp 2008). When barley was substituted for corn in lactating cow rations, various factors such as production, composition, intake, and feed efficiency parameters were not significantly impacted by the type of grain used (Bilodeau et al. 1989; DePeters and Taylor 1985). Similarly, research on oats has shown that oats can be substituted in the diets of hogs and lactating/gestating cows without affecting feed efficiency, feed intake, daily weight gain, and other factors (Honeyman, Sullivan, and Roush 2002; Myers 2000). Therefore, similar to the expansion of the market for DDGS, the market demand for small grains can increase as well if there is abundant supply and efforts are made towards research and market promotion. While the corn ethanol boom intensified the concentration on corn and exacerbated the economic risks and water quality problems associated with corn ethanol (Martin 2011), expanding markets for small grains and alfalfa will reduce the concentration on corn and benefit water quality.

Appendix 4: Modeling Assumptions on Feed Substitution

Our model incorporates the assumption that a small percentage of today's feed demand for corn would be replaced by oats/alfalfa initially, with the remaining cropland in Iowa planted under prevailing agricultural practices.[1] It is expected that with an influx of oats/alfalfa in the market at a lower price, livestock producers will adjust their feed rations so that some of the corn in their feed ration is substituted with oats, thus increasing the demand for oats and reducing the demand for corn.[2] Clearly, other markets would be involved as well; however, our simple model uses no iterative process where demand from other markets such as livestock and dairy responds to the increased supply. A more comprehensive model where dairy and livestock markets are modeled would be needed to get at the exact impact.

To estimate the percentage of corn production currently used as animal feed, we used the corn-use calculator developed by Iowa State University extension and outreach (***www.extension.iastate.edu/agdm/livestock/html/b2-55.html***) (Lammers, Hart, and Honeyman 2012). This tool uses a combination of statistics on Iowa livestock and poultry populations with livestock production budgets to calculate feed used under various scenarios. The calculator used livestock and poultry population data from 2006 to 2010 from USDA. We updated the data for these years and added data for the years 2011–2015 (Iowa State University 2016). Using the calculator, we estimated the amount of corn used as feed for each year from 2008 to 2015 and used the average as the quantity of feed demanded for the period 2008-2015.

The model's calculation of the amount of feed that could be replaced in livestock rations was based on previous studies by Honeyman, Sullivan, and Roush (2002) and Myers (2000). Honeyman, Sullivan, and Roush looked at performance of market hogs in deep-bedded hoop barns when an addition of 20 percent and 40 percent oats was 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 percent or the 40 percent oats in hog diets. Since this study considered mostly the percentage of oats that could be substituted for corn and considered only very small percentage of oats substitution for soymeal, we did not consider substitution of oats for soybeans. In reality, more oats could be substituted for some of the soybean than what we modeled, increasing the oats demand further, but here we made a conservative case.

Another study (Myers 2000) found that oats can constitute up to 25 percent of the diet for pigs under 60 pounds and up to 40 percent for growing-finishing swine without significant decrease in the rate of weight gain. However, because of the lower concentration of energy in oats, daily feed intake and feed required per pound of weight gain increase as the level of oats in the diet is increased. The study also found that oats can constitute the sole grain source in diets. However, for optimal results, oats should not compose more than 50 percent of the sows' diet. Because of lactating sows' high energy requirements, the level of oats in their diets should not exceed 20 percent.

In our first analysis—scaling up of diverse rotation systems specifically on the most erosive cropland in Iowa—we considered the amount of feed substitution that would be needed if we transformed the corn/soy acres (3.6 million acres)[3] in the 25 most erodible counties to diverse systems given the supply/demand dynamics. We experimented with 5 percent and 10 percent levels of substitution in this case. In our second analysis—of the extent to which diverse systems could be scaled up across the state of Iowa—we considered 20 percent (three-year rotation), 25 percent (four-year rotation), and 40 percent (three-year and four-year rotation) feed substitution cases based on prior studies outlined above which specify the extent to which small grains can be substituted for corn in livestock diets.[4]

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[1] The dominant crops planted in Iowa are corn and soybean. The number of acres of corn and soybean planted on the remaining acres (acres not allocated to diverse rotation) is based on the relative proportion of corn acreage and proportion of soybean acreage planted from 2008 to 2015. The yields we used are average corn and soybean yields, reported annually by the National Agricultural Statistics Service (NASS), for the period 2008–2015 (NASS 2016).

[2] While no demand or production information is available for oat straw, we assume that the additional oat straw can be sold on the market.

[3] Average corn acres for the period 2008-2015 based on NASS county level data. (NASS, 2015)

[4] In the four-year rotation with 25 percent feed substitution, oats would substitute 15 percent and alfalfa 10 percent of the feed ration. In the four-year rotation with 40 percent feed substitution, oats would substitute 20 percent and alfalfa 20 percent of the feed ration.

Appendix 5: Methodology for Estimating Change in Soil Erosion Using the Daily Erosion Project Model

The Daily Erosion Project (DEP) model produces daily estimates of hillslope soil detachment, hillslope soil loss (or soil delivery to the hillslope base), and hillslope water runoff using the Water Erosion Prediction Project (WEPP) model (Cruse et al. 2006).[1] The estimates are made for modeled individual hill slopes and then aggregated to the watershed scale (at the Hydrological Unit Code HUC12 scale, approximately township-sized watersheds) for public/research consumption. During the period 2008–2015, expansive areas of Iowa had estimated soil erosion rates well in excess of the USDA's dominantly used tolerable soil erosion rate of five tons per acre per year. Selected areas experienced estimated soil erosion rates up to 10 times this rate (which itself exponentially exceeds the levels known to be actual soil replacement rates). We calibrated the model to these current conditions and used it to calculate the impact of changing hill slope sheet and rill erosion associated with converting baseline soil management practices (dominantly corn and soybean) in Iowa for the 2008–2015 period to either a three- or four-crop rotation explained fully in Burkart et al. (2005) and summarized below. The change in erosion reported is the difference in soil erosion estimates from the DEP baseline runs for the 2008 through 2015 period.

Four-year rotation: This management practice includes a four-year rotation of oats + alfalfa, alfalfa, corn, and soybean. Tillage operations include moldboard plowing, disking, and field cultivating from alfalfa to corn and disking and field cultivating from corn to soybean and soybean to oats.

Three-year rotation: This management practice includes a three-year rotation of oats + clover (simulated as alfalfa due to their similarities), corn, and soybean. Tillage operations include moldboard plowing, disking, and field cultivating from clover to corn and disking and field cultivating from corn to soybean and soybean to oats.

These two rotations were configured such that an equal proportion of each phase of the rotation was present in a given HUC12 for a given year. For example, if one phase of the four-year rotation was presented by OACS (oats, alfalfa, corn, soybean), then 25 percent of the hillslopes would be in OACS, 25 percent in ACSO, 25 percent in CSOA, and the last 25 percent in SOAC. This should avoid any biases caused by heavy rainfall years in the record. All baseline hillslopes were converted to these two scenarios for the purposes of a full comparison against baseline. The consideration of which HUC12s represented the top 25 percent of the most erosive soil areas was left to a post-processing step. The DEP runs were made independently, with individual hillslope results saved for aggregation. These two rotations were subsequently modified to include a no-till only management practice to provide an additional two scenarios for this comparison.

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[1] See ***https://dailyerosion.org/*** for details on the DEP. WEPP is an erosion simulation model based on the fundamentals of hydrolics, hydrology, plant science, and erosion mechanics. See ***www.ars.usda.gov/midwest-area/west-lafayette-in/national-soil-erosion-research/docs/wepp/research/*** for details.

Appendix 6: Calculation of Environmental Benefits

Calculation of Nitrous Oxide (N_2O) and Carbon Dioxide–Equivalent (CO_2)[1]

Many studies on nitrogen (N) input in row-crop agriculture have found that there is a strong correlation between fertilizer N rate and emissions of N_2O, a potent greenhouse gas (e.g. Drury, et al. 2008; Dusenbury, et al. 2008; Halvorson, Del Grosso, and Reule 2008; Mosier, et al. 2006; McSwiney and Robertson 2005; Bouwman, Boumans, and Batjes 2002; MacKenzie, Fan, and Cadrin 1998). All of these studies found that increased addition of N to the soil led to increased N_2O emissions.[2] To estimate the reduction in emissions due to reduction in fertilizer N rate as a result of switching from a two-year C-S rotation to a more diverse three- or four-year rotation, we used the methodology developed by Millar, et al. 2010. This study is based on field studies in the state of Michigan that looked at the response of a large number of fertilizer applications in corn cropping systems. The field sites used in that study to determine the N_2O nonlinear response for Michigan are a broad representation of corn rotations and soil conditions throughout the Midwest. Below we describe the methodology used to calculate the annual reduction of N_2O direct emissions from the corn component of a C-S-O rotation and C-S-O-A rotation due to reduction in fertilizer N rate (both synthetic and manure). This reduction is a result of switching from a two-year C-S rotation to a more diverse three- or four-year rotation based on the data from the Iowa State University study.

Emissions reductions of N_2O due to reduction in annual fertilizer N rate using the Iowa State organic and inorganic applied N rates was calculated as:

$$N_2O_R = N_2O{+}_{N(Before)} - N_2O{+}_{N(After)} \tag{1}$$

where

N_2O_R = reduction in emissions due to fertilizer N rate reduction, kg CO_2-e $ha^{-1}yr^{-1}$

$N_2O{+}N_{(Before)}$ = direct emissions following N fertilizer input before fertilizer N rate reduction, kg CO_2-e $ha^{-1}yr^{-1}$

$N_2O{+}_{N(After)}$ = direct emissions following N fertilizer input after fertilizer N rate reduction, kg CO_2-e $ha^{-1}yr^{-1}$

Following Millar, et al. 2010, we use two approaches—a linear and a non-linear approach—to estimate N_2O emissions. The linear approach assumes a linear response between N and emissions and is the method proposed in the Intergovernmental Panel on Climate Change protocol. The non-linear approach assumes that the response between N and emissions is non- linear and therefore emissions are higher. Equation 2 below was used to estimate emissions from both the approaches.

$$N_2O{+}N_{(Before/After)} = [(F_{SN}+F_{ON})_{(Before/After)} * E_{FN}) + N_2O_{0N(Before/After)}] * N_2O_{MW} * N_2O_{GWP} \tag{2}$$

where

$N_2O{+}_{N(B\ Before\ /After)}$ = direct N_2O emissions following N fertilizer input, kg CO_2-e $ha^{-1}yr^{-1}$

$N_2O_{0N(Before\ /\ After)}$[3] = direct N_2O emissions following zero (0) fertilizer N input, kg N_2O –N $ha^{-1}yr^{-1}$

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[1] For any quantity and type of greenhouse gas, CO_2-e signifies the amount of CO_2 that would have the equivalent global warming impact.

[2] This result has been used as the basis for IPCC (2008) greenhouse gas inventory calculations.

[3] 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

$F_{SN\ (Before\ /After)}$ = mass of N applied from synthetic fertilizer, kg N $ha^{-1}yr^{-1}$

$F_{ON\ (Before\ /After)}$ = 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}[4] = global warming potential for N_2O, kg CO_2-e (kg N_2O)$^{-1}$

EF_1: The IPCC tier 1 default emission factor (EF_1) has a value of 0.01 or 1.0% (IPCC 2008) 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, is sensitive to N rate and can be expressed as:

$EF_2 = 0.012 * \exp [0.00475 * (F_{SN}+F_{ON})]$

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.

Calculation of N_2O Emissions

Linear: N_2O-N[5] = 1.47 + (0.01 * fertilizer N rate)
Non-linear: N_2O-N = 1.47 + [(exp * 0.0082 * fertilizer rate)]

The results of the estimation are reported in Table 2 and 4 of the report. Only the results of the non-linear method are reported in the table even though estimation was done using both linear and non-linear methods. This is because various studies indicate that the linear method is unsuitable for estimating emissions in Midwest agriculture, where the response between nitrogen and emissions is non-linear. We found that the linear model results in CO_2-equivalent reductions of 0.038 ton/acre and 0.044 ton/acre for the corn-soy-oats and corn-soy-oats-alfalfa systems, respectively.

Using the non-linear models results in CO_2-equivalent reductions (0.17 ton/acre and 0.20 ton/acre for the corn-soy-oats and corn-soy-oats-alfalfa systems, respectively), we estimated the reduction in emissions as follows:

N_2O –N $ha^{-1}yr^{-1}$. When we compared N_2O emissions between the linear and non-linear methods, this value for N_2O emissions from the zero fertilizer rate control was used in both methods.

[4] The global warming potential value of 298 for N_2O was used. This is the 100-year value used in the IPCC Assessment Report (Forster et al. 2007), and is the direct global warming potential 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).

[5] The conversion of N_2O–N (the mass of the nitrogen component of the nitrous oxide molecule) to N_2O (N_2O_{MW}) 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 N_2O molecule, i.e., $N_2O = N_2O –N×44/28$.

Reduction in emissions = CO_2-equivalent reductions (ton/acre) × acres converted to corn-soy-oats/corn-soy-oats-alfalfa.

The dollar value of reduced CO_2 emissions was calculated as follows:

Reduction in emissions × social cost of carbon ($36/ton) (EPA 2016).

Carbon Sequestration Benefits

Though the rates of carbon sequestration from different agricultural practice 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 and with crop rotation could be an average of 0.29 metric ton/acre (The Nature Conservancy 2016). We used the average of these two numbers (0.39 metric ton/acre).

Using the estimate above, we estimated CO_2 sequestered as follows:

CO_2 sequestered = (0.39 * acres converted to a three-year no-till/four-year no-till rotation)

The dollar value of CO_2 sequestered = CO_2 sequestered × social cost of carbon ($36/ton).

Surface Water Cleanup Costs

According to the Natural Resources Conservation Service, for every ton of soil erosion prevented, water cleanup costs are reduced by $5.69/acre in 2016 dollars ($4.93/acre in 2007 (NRCS, 2009)).

To estimate surface water cleanup costs, we first estimated the soil saved per acre using percentage reduction in soil erosion and the base erosion rates. Both are from the DEP model (Tables 1 and 3 in the report).

Surface water cleanup costs were estimated as follows:

Soil saved per acre * $5.69 * acres converted to a three-year no till/ four-year no till rotation

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