Illinois Farmers' Beliefs about the Maximum Return to Nitrogen (MRTN) Recommendation

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Abstract

A new nitrogen recommendation technology called the Maximum Return to Nitrogen (MRTN) recommendation was introduced in 2005 by Midwest Land Grant Universities after research showed yield-based recommendations were often too high for soils. However, adoption of the MRTN recommendation by Illinois farmers appears low and applying nitrogen at rates above the recommended rate is still prevalent despite the water quality and environmental implications. This analysis uses field-level data from Precision Conservation Management (PCM), a farmer service program led by the Illinois Corn Growers Association and Illinois Soybean Association to identify some factors that influence the use of the MRTN in Illinois. Within the data, 70% of corn fields receive a nitrogen application above the MRTN profitable range. We find the main factors that increase the probability of MRTN adoption are if the field is enrolled in a NRCS program or if the field is planted in cover crops. We find the main factors that decrease the probability of MRTN adoption are if the field receives a custom application by a retailer or if the field receives a fall nitrogen application.

Keywords: technology adoption, MRTN, nitrogen, corn

Introduction

The development of the Haber-Bosch process in 1909 which converts atmospheric nitrogen to synthetic fertilizers have been key in maintaining growth of corn yields. Since 1909, corn yields in the United States have increased by more than six-fold, with nitrogen fertilizer technology working together with genetics and other technologies to support the significant increase in agricultural productivity (Melillo 2012; NASS QuickStats). The increase in agricultural productivity is important, as the world population increased from 1.8 billion in 1909 to more than seven billion today. Without the Haber-Bosch process, it is suggested that at least 2 billion people would not be alive today (Smil 2001).

However, use of nitrogen fertilizer has implications for water quality, climate change, plants and animals, and human health. Applying nitrogen at rates above the recommended amount seems to be prevalent across the United States despite the drawbacks from overapplication (Roy et al. 2021; Ribaudo et al. 2011). Excess application of nitrogen harms farmer profitability, as increasing application without a corresponding yield increase results in lost profit. Farmers use various private and public sources of information to make nitrogen fertilizer application decisions, including university nitrogen recommendations. In 2004, researchers from Midwest Land Grant Universities met to develop a new nitrogen recommendation called the Maximum Return to Nitrogen (MRTN). The MRTN recommendation typically resulted in lower nitrogen application levels than the previous yield-based university recommendations (Nafziger 2017). Conversations with farmers and industry professionals suggest the adoption of the MRTN recommendation system has been low in Illinois. This leads to the question: if applying nitrogen at rates above the university recommended level has negative financial and environmental impacts, why do farmers apply nitrogen at rates above the university recommendation?

The production of synthetic ammonia by the Haber-Bosch process requires a large amount of energy and accounts for more than 50 percent of the energy used in commercial agriculture (Woods et al. 2010). Transformation of ammonia into other nitrogen products such as urea and urea-ammonium nitrate (UAN) requires additional energy, and all forms of nitrogen have costs related to transportation and storage at fertilizer terminals. After the application of nitrogen to fields, the chain of environmental impacts continues as nitrogen loss occurs through leaching, volatilization, and denitrification. Inorganic nitrogen is lost in the water through leaching and runoff in the form of ammonium, nitrate, dissolved organic nitrogen, and particulate organic nitrogen, and in the air through volatilization and emission of gasses in the forms of ammonia, nitrogen oxides, including nitrous oxide, and dinitrogen gas (Zhang et al. 2015).

In Illinois and across the Midwestern United States, there has been a focus on nitrogen losses to water bodies. Nutrient losses harm drinking water quality and aquatic life and stimulates growth of harmful algal blooms (IEPA et al. 2015). Nutrients lost from agricultural fields leave Illinois through our river systems and much is ultimately deposited into the Mississippi River, where they then travel to the Gulf of Mexico. At the Gulf, the nutrients cause excessive growth of algae which die and decompose resulting in depleted oxygen levels, causing a sizeable and growing hypoxic zone. The hypoxic zone changes the biology of the region and harms marine life (U.S. EPA 2008). In Illinois, it is estimated that 80% of the nitrate-nitrogen contributed to the Mississippi River from point and nonpoint sources comes from agricultural fields (IEPA et al. 2015).

Task forces at the federal and state levels in some states exist to provide nutrient loss reduction strategies. At the federal level, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force has a goal to reduce the size of the hypoxic zone to less than 5,000 square kilometers by 2035 with an interim target of a 20% reduction of nitrogen loading by 2025 (U.S. EPA 2014) In Illinois, *The Illinois Nutrient Loss Reduction Strategy* was released in 2015 with a goal to reduce total nitrogen loads to Illinois water bodies by 45% by 2035, with an interim goal of 15% nitrate-nitrogen reduction by 2025 (IEPA et al. 2015). However, the estimated statewide average annual nitrate-N load from 2013-2017 in Illinois rivers was approximately 7% greater than the 1980-1996 baseline average (IEPA et al. 2019).

Economic pressure is a challenge for farmers. Farmers may view adding extra nitrogen fertilizer as a way to ensure high yields and economic stability (Stuart, Schewe, and McDermott 2014). Selecting a nitrogen rate is a delicate balance between overapplying and underapplying where overapplying results in lost money spent on unused nitrogen, while underapplying results in lost profit opportunities from decreased yield. In a scenario described by Ribaudo et al. (2011) with two states, ideal conditions and non-ideal conditions, if a farmer applies 179 pounds of nitrogen, they expect 170 bushels per acre of corn under ideal conditions and 148 bushels per acre under non-ideal conditions. The farmer could use 165 pounds per acre of nitrogen under non-ideal conditions and get 148 bushels per acre. Suppose the weather conditions turn out to be ideal. In that case, the farmer will miss out on an extra 22 bushels per acre, resulting in a $99 per acre loss at a corn price of $4.50 per bushel, while the extra nitrogen applied only costs $7 per acre at a fertilizer price of $0.50 per acre The benefits of reducing nitrogen application depend on the amount of overapplication. Assuming 10 percent of producers overapply nitrogen, reducing nitrogen application by 20 pounds per acre to the MRTN rate results in an $8 per acre savings (IEPA 2015). Cost savings may not cover the potentially large financial loss resulting from the underapplication of nitrogen.

Previous research in the agricultural economics literature focuses on the adoption of nitrogen-efficient technologies such as nitrogen soil testing, plant tissue testing, nitrogen transformation inhibitors, and variable rate technology (Khanna 2001; Weber and McCann 2014). This paper investigates the technology adoption decision of the MRTN nitrogen recommendation using a unique field-level panel dataset of farmers enrolled in Precision Conservation Management (PCM). PCM is a farmer-service program led by the Illinois Corn Growers Association and Illinois Soybean Association developed to help farmers reduce nutrient losses in a profitability-focused manner. This is the first paper to investigate the MRTN as a farmer technology adoption decision.

Background

For decades, Land Grant Universities have served as a source of nitrogen recommendations for farmers who must make nitrogen application decisions for their corn each year. Before 2004, a yield-goal-based nitrogen recommendation system called the proven-yield (PY) method was the standard in Illinois, with farmers advised to follow the rule “1.2 is the most [we] should do (Fernández et al. 2009, 113).” The proven-yield method involved estimating the field’s yield under the most favorable growing conditions and then applying nitrogen at the rate of 1.2 multiplied by the field’s yield estimate. However, subsequent research began to show yield-based recommendations were often too high for Illinois soils, with little or no relationship between nitrogen rates and yields at those levels. Based on these findings, a new nitrogen recommendation system was needed (Fernández et. al. 2009). A group of researchers met in 2004 to address this problem, resulting in the MRTN approach to nitrogen recommendations

(Nafziger 2017). The MRTN approach fits a curve through nitrogen trial data obtained from research sites across Illinois, calculating the “(net) return to N” (RTN) yield across a range of nitrogen rates. Individual curves plotting nitrogen application rate (lb N/acre) against return to nitrogen ($/acre) are created for different regions and preceding crops, and the nitrogen rate associated with the high point on each curve is determined to be the “maximum return to N (MRTN)” rate for that system/region. A “Profitable N Rate Range” is also provided, calculated as the N rate values for $1/acre net return above and below the MRTN value (Nafziger 2018). Nitrogen recommendations provided by land grant universities face scrutiny because of concern over the effect of agricultural nitrogen use on water quality and the contribution of agricultural nitrogen to elevated groundwater nitrate concentrations (Sawyer et al. 2006).

Within the PCM dataset, 70% of corn fields receive a nitrogen application above the MRTN rate. In the Illinois Nutrient Loss Reduction Strategy survey conducted by NASS, results show farmers used the MRTN to help determine nitrogen application rates on 70% of their planted acres in 2011 and 81% of their planted acres in 2015. However, when the survey added the option to select “other-industry recommended technique” in 2017, the number of farmers using the MRTN decreased to 33% of acres, and another industry-approved technique was used on 69% of planted acres (IEPA et al. 2019). Farmers could select two or more strategies, so the sum of percentages is greater than 100. Farmers may apply nitrogen at the MRTN recommended level but forget to count other nitrogen sources they apply. The most commonly used phosphorous fertilizers, diammonium phosphate (DAP) and monoammonium phosphate (MAP), contain nitrogen due to their derivation from ammonia. Nitrogen fertilizers can also be used as a carrier when applying certain herbicides, so farmers may be unintentionally overapplying by not factoring these nitrogen sources into their total nitrogen application.

Literature Review

The technology adoption literature is multidisciplinary (Weber and McCann 2014). The literature related to nitrogen technology adoption typically falls into three categories: agronomists who focus on the performance of the nitrogen recommendation technology, economists who focus on the farmer technology adoption decision, and sociologists who investigate farmers' use and perceptions of the technology, with multidisciplinary work between the groups often taking place. Within the economics literature, two important aspects of technology adoption are the rate of technology adoption and the characteristics of the adopters. An S-shaped curve, characterized by four periods: early adoption, takeoff, saturation, and decline, represents the diffusion of agricultural technologies (Sunding and Zilberman 2001). Farmers typically fall into three groups: early adopters who profit from the adoption decision, followers who adopt during the takeoff stage and may gain or lose from adoption, and laggards who adopt during the decline stage or do not adopt all (Cochrane 1979).

One way to define innovation is as a technological factor that changes the production function and about which some perceived or actual uncertainty exists. The uncertainty decreases over time as individuals acquire information and experience, and the assumption here is the innovation diffusion process is dynamic (Feder and Umali 1993). The classification of innovations includes mechanical, biological, chemical, agronomic, biotechnological, and information innovations (Sunding and Zilberman 2001). Studies about technology adoption typically focus on either the adoption decision at the firm level or significant characteristics about the adopters of technologies (D'Souza, Cyphers, and Phipps 1993). The focus depends on whether the researcher is viewing technology adoption as a micro or macro process. The micro-level focuses on the individual's decision to adopt. The macro-level focuses on the adoption pattern of the whole firm or household to identify trends in the diffusion cycle of the innovation (Feder and Umali 1993). Many studies have focused on agricultural technology adoptions such as hybrid corn (Griliches 1957), reduced tillage (Rahm and Huffman 1984), irrigation technology (Caswell and Zilberman 1986), and Integrated Pest Management (IPM) (McNamara, Wetzstein, and Douce 1991).

Some researchers believe U.S farmers apply more nitrogen than required by the equation of marginal product and factor costs, suggesting farmers could reduce input levels without yield losses. However, economically rational reasons may exist for applying extra nitrogen (Babcock 1992). According to Sheriff (2005), the main reasons farmers apply more nitrogen than agronomically recommended are farmer perception of agronomic advice, input substitutability, hidden opportunity costs, and uncertainty. Farmers may believe the extension advisor's model is incorrect or their field is different from the model. One study finds that Texas sorghum producers' yield expectations were greater than the yield response observed, suggesting farmers may overestimate the yield response to nitrogen fertilizer (SriRamaratnam et al. 1987). Because water, nitrogen, and phosphorous are considered complementary, farmers who expect significant rainfall in a year may apply more nitrogen fertilizer than farmers who do not expect significant rainfall. Farmers may undervalue their farm labor and equipment costs related to nitrogen application. Also, nitrogen is believed to be less expensive in the fall, so fall over-application may seem more profitable to farmers, especially if the difference in cost between fall and spring nitrogen is greater than the value of the lost nutrients from fall nitrogen application. Nitrogen application depends on the farmers' risk preferences and whether they perceive nitrogen as a risk-reducing or risk-enhancing input (Sheriff 2005). Farmers may also apply extra fertilizer due to weather and soil nitrogen level uncertainty. Farmers may self-protect by increasing nitrogen fertilizer applications to reduce the probability they are “caught short” of fertilizer (Babcock 1992).

Farmers may consult various public or private sources of information when making their nitrogen application decision. Farmers often view their fertilizer dealer as the most important source of information for making nitrogen application decisions (Stuart, Schewe, and McDermott 2014; Houser et al. 2019; Marks and Boerngen 2019). Houser et al. (2019) find that fertilizer dealers, independent crop consultants, and Extension are the most often used information sources for a sample of commercial corn producers in Indiana, Iowa, and Michigan, with fertilizer suppliers perceived as the most important source. A study of Michigan farmers by Stuart, Schewe, and McDermott (2014) finds 77% of survey respondents never use the university recommendation when making fertilizer application decisions.

Data

The data for this study come from Precision Conservation Management (PCM). PCM is a farmer service program led by the Illinois Corn Growers Association and Illinois Soybean Association in partnership with over 30 entities, including other commodity associations, conservation groups, private foundations, supply chain providers, the Soil and Water Conservation Districts, and the Natural Resources Conservation Service (NRCS). In an effort to address the goals of the Illinois Nutrient Loss Reduction Strategy, the mission of PCM is to help farmers make decisions about adopting on-farm conservation practices in a financially responsible way. Through PCM’s regional specialists, PCM works one-on-one with over 330 farmers enrolled in its 16-county service area, representing over 300,000 acres of Illinois farmland. Figure 1 shows the service area PCM currently covers in Illinois.

Figure 1. Precision Conservation Management (PCM) Service Area

Source: PCM website

The PCM data are self-reported by farmers via an online data collection platform with assistance from PCM's Precision Conservation Specialists. The sixteen-county service area in Illinois is divided into four regions with a Precision Conservation Specialist assigned to each region. The Precision Conservation Specialists offer one-on-one technical support for farmers, compile and review farm reports, and assess farm data to ensure data quality and accuracy. The farmer reports all operations for each field they enrolled in the PCM program. This includes any applications or field passes made on the field throughout the growing season, amount and types of inputs applied, and yield. The anonymized and aggregated data are used to provide reports to farmers to help them make business decisions about adopting conservation practices with a focus on financial and environmental comparisons.

PCM collects data about all inputs used, agricultural practices performed, and yields for each field but does not collect crop price and input cost data from the farmers. Instead, standard prices and costs are uniformly applied to all fields. Multiplying the field's yield by a standard yearly price results in revenue from crop sales that is the same across all farms. Multiplying actual input amounts by a standard input price provides the direct costs. These costs include seed, fertilizer, pesticide, drying, storage, and crop insurance. Assigning field passes a cost based on Machinery Cost Estimates from the University of Illinois and summing the costs represents machinery-related power costs. Overhead costs are based on Illinois Farm Business Farm Management Association (FBFM) data and are the same for all farms. Subtracting costs from revenue results in operator and land return, a measure of return for farmland. Operator and land return does not include a land cost. Subtracting off a land cost, such as cash rent, would give a farmer net return. Using the same costs and prices for all farmers removes the effect of farmer grain marketing skill, volume discounts on input purchases based on farm size, and negotiating skills from the data. The historical data changes from year-to-year because as new farmers are added to the program, they share both current and historical production records.

A subset of this data are used in this analysis. The subset is representative of the typical practices that occur on Central Illinois corn fields. The PCM data used in this research consists of all corn fields without manure applications and planted following soybeans the previous year from 2015-2020, representing a total of 1,726 unique fields and over 144,633 acres. Of the total unique cornfields, 1,166 (68%) of the fields are classified as high productivity soil, with a Soil Productivity Rating above 130.

This analysis uses the Maximum Return to Nitrogen (MRTN) recommendation from Land Grant Universities. Each year, the PCM specialists give the MRTN rates to the farmer before the farmer makes their yearly nitrogen application decision. The MRTN also includes a profitable nitrogen range that represents the nitrogen rate values at a $1 per acre net return range around the MRTN. Applying nitrogen within the profitable nitrogen range would provide a similar expected economic return as the MRTN. Table 1 displays the MRTN and profitable nitrogen range.

Table 1. MRTN and Profitable Nitrogen Ranges for PCM Farmers[1]

Year	MRTN (lbs. of actual N/acre)	Profitable Nitrogen Range (lbs. of actual N/acre)
2015	163	148 – 177
2016	168	154 – 184
2017	172	158 – 189
2018	176	161 – 193
2019	173	158 – 189
2020	184	169 – 200

[1] Assume the region is Central Illinois, and the following nitrogen to corn price ratios: 0.11 for 2015, 0.10 for 2016, 0.09 for 2017, 0.08 for 2018, 0.09 for 2019, and 0.08 for 2020.

Empirical Strategy

Researchers commonly use random effects probit and logit models for analyzing panel data with a binary dependent variable (Bland and Cook 2019). The results of the Hausman test and Chamberlain-Mundlak device suggest the random effects model is appropriate to use for the data. Following Li, Vyn, and McEwan (2016), to investigate the factors influencing farmers' adoption of the MRTN recommendation technology, we use the panel data to estimate the following random effects Probit model:

$$MRTN_{it} = \theta x_{it} + u_i + v_{it}$$

Where $MRTN_{it}$ take the value $MRTN_{it} = 1$ if the field received a nitrogen application within the MRTN recommended range and 0 otherwise. The x_{it} denotes a vector of explanatory variables, u_i denotes a time-invariant component capturing field-specific unobserved heterogeneity, and v_{it} given (x_{it}, u_i) has a Normal $(0, \sigma_v^2)$ distribution. Table 2 presents the descriptive statistics for all variables used in the empirical analysis.

Table 2. Descriptive Statistics for Variables Used in MRTN Technology Adoption Model

Variable	Definition	Mean	S.D.	Min	Max
Dependent Variable					
MRTN	= 1 if field received a nitrogen application in MRTN recommended range	0.262	0.440	0	1
Explanatory Variables					
Custom	= 1 if field received any nitrogen application custom applied by a retailer	0.161	0.368	0	1
Conservation	= 1 if field received conservation tillage	0.686	0.464	0	1
Cover	= 1 if field planted in cover crops	0.085	0.279	0	1
Fall	= 1 if field in the Fall Nitrogen Benchmark	0.279	0.449	0	1
NRCS	= 1 if field in NRCS program	0.175	0.380	0	1
Pesticide	Pesticide applied cost in dollars per acre	59.83	21.67	0	133.00
VRT	= 1 if field had any application with Variable Rate Technology (VRT)	0.244	0.429	0	1

Table 3 presents the summary statistics by nitrogen recommendation. On average, there is less custom applied nitrogen, more conservation tillage, more cover crops, less fall applied nitrogen, more NRCS program enrollment, higher pesticide costs, and more VRT on fields where the MRTN was used compared to fields where the MRTN was not used. Conservation tillage indicates the field is in the no-till, strip-till, or one-pass-light PCM tillage benchmark. The fall nitrogen benchmark indicates that more than 40% of the total nitrogen application occurred in the fall on the field.

Table 3. Descriptive Statistics for Variables Used in MRTN Technology Adoption Model by MRTN Category

		MRTN		Non-MRTN	
Variable	Definition	Mean	S.D.	Mean	S.D
Custom	= 1 if field received any nitrogen application custom applied by a retailer	0.126	0.332	0.174	0.379
Conservation	= 1 if field received conservation tillage	0.749	0.434	0.664	0.472
Cover	= 1 if field planted in cover crops	0.134	0.341	0.068	0.251
Fall	= 1 if field in the Fall Nitrogen Benchmark	0.263	0.440	0.285	0.452
NRCS	= 1 if field in NRCS program	0.256	0.437	0.147	0.354
Pesticide	Pesticide applied cost in dollars per acre	63.42	21.76	58.55	21.50
VRT	= 1 if field had any application with Variable Rate Technology (VRT)	0.261	0.440	0.238	0.426

Results

Table 4. Regression Results for MRTN as a Technology Adoption Decision

Custom	-0.196*
	(0.104)
Conservation	0.195**
	(0.083)
Cover	0.409***
	(0.125)
Fall	-0.169**
	(0.084)
NRCS	0.461***
	(0.098)
Pesticide	0.006***
	(0.002)
VRT	0.040
	(0.083)
Constant	-1.35***
Observations	2,343
Log lik.	-1,294
LR test [p-value]	24.33
	[<0.001]

Note: Standard errors in parentheses. Asterisks denote:

*$p < 0.10$, ** $p < 0.05$, and ***$p < 0.01$

Table 5. Marginal Effects

Custom	-0.049*
	(0.026)
Conservation	0.049**
	(0.021)
Cover	0.102***
	(0.031)
Fall	-0.043**
	(0.021)
NRCS	0.116***
	(0.023)
Pesticide	0.001***
	(0.000)
VRT	0.010
	(0.021)

Note: Standard errors in parentheses. Asterisks denote:

*$p < 0.10$, ** $p < 0.05$, and ***$p < 0.01$

Table 4 presents the results for the random effects probit estimates of how factors influence the probability of adopting the MRTN recommendation. Results suggest the likelihood of adopting the MRTN recommendation technology is higher for fields with conservation tillage, cover crops, and a NRCS program. The likelihood of adopting the MRTN recommendation technology is lower for fields with custom applications by a retailer and fall nitrogen.

Table 5 displays the average marginal effects for the explanatory variables. When considering the average marginal effects, the largest increases in the probability of adopting the MRTN are fields enrolled in a NRCS program and fields planted with cover crops. On average, if the field is enrolled in a NRCS program, this increases the probability of adopting the MRTN recommendation by 12%. Planting the field in cover crops, on average, increases the probability of adopting the MRTN recommendation by 10%. This suggests fields exposed to an NRCS program and the related information are more likely to adopt the MRTN. The probability of adopting the MRTN decreases when the field has a custom application by a retailer or the field receives a fall nitrogen application. On average, if the field receives a custom application from a retailer, the probability of adopting the MRTN recommendation decreases by 5%. If the field receives a fall nitrogen application, on average, the probability of adopting the MRTN recommendation decreases by 4%.

Conclusion

Although the Maximum Return to Nitrogen (MRTN) recommendation was developed more than fifteen years ago, farmer adoption of this technology has been relatively slow. This paper aims to identify some factors which increase or decrease the probability of adoption of the MRTN by using a unique field-level dataset from Central Illinois. We find the main factors that increase the probability of MRTN adoption are if the field is enrolled in a NRCS program or if the field is planted in cover crops. We find the main factors that decrease the probability of MRTN adoption are if the field receives a custom application by a retailer or if the field receives a fall nitrogen application. Understanding the factors that influence nitrogen recommendation technology adoption can help researchers to share information with farmers and encourage the use of new nitrogen recommendation technologies.

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