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The Economic Evaluation of Input Use Prescription Maps: Are You Paying to Make Less Profit?

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The Economic Evaluation of Input Use Prescription Maps: Are You Paying to Make Less Profit?

by

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ECONOMICALLY OPTIMUM SEEDING AND NITROGEN RATES:

ARE CONSULTANTS PRESCRIPTIONS ACCURATE?

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Variable Rate Prescriptions used by farmers to apply agricultural inputs are largely privatized and are normally seen only by the farmer that applies the prescription and the consultants whom create the prescription maps. Farmers need a way to evaluate the prescriptions that are being applied to fields. This paper explores modeling techniques which could be applied by farmers to determine the profitability of a particular consultant. Regression modeling is used on field trials which have been divided into site-specific management zones (SSMZ) based on a consultant's variable rate prescriptions. Production functions are created for each management zone. The production functions are used to find the economically optimum rates or the rates which maximize profit. The consultant's rates are also explored to determine how close this particular consultant is to the economically optimum rates. The consultant that is evaluated in this paper produces a profit that is $11 less than the economically optimum rates.

Dedication

First and foremost, I want to dedicate this thesis to my Lord and Savior, Jesus Christ. Moving to Nebraska and continuing my education was one of the most difficult decisions of my life. It caused a lot of stress, but I now know that God put me here for a reason. I have made some of my best friends, expanded my educational horizons, and completed projects that I did not think were possible. All glory goes to Him.

I also want to thank my friends and family. My family members, mom and dad specifically, have always pushed me to be the best and are my support system. I could not have made it through the past few years without their assistance, whether that was emotional, physical, or monetary. I also want to thank my friends in Indiana and Nebraska. I have the best friends ever. I cannot name all of them, but they know who they are. Mikaela, I would not have made it through my first year and a half without you. Also, shout out to the Settje's for treating me like a member of the family. You are the best.

I want to thank Taro for choosing to work with me and pushing me to excel in the UNL Agricultural Economics Master's program. I know my questions irked him at times, but he was always patient and wanted me to succeed. He taught me everything I know about 'R' and this thesis would not have been possible without it.

Last, I want to give a shout out to Spotify for the countless hours of music. I would not have survived the daily thesis grind without it.

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Chapter 1: Introduction

Recent farming has been influenced heavily by the data revolution made possible by the invention of precision agriculture technologies, including yield monitors, variable-rate applicators, remote and proximal sensors, and GPS-guided automated operations. Scientists have been exploring numerous ways for farmers to properly use the resultant ever-expanding data to fine-tune the site-specific input management strategies. Currently, variable rate technology (VRT) is commonly used to manage many farming inputs, including seed, fertilizers, and irrigation. But most farmers do not feel technically advanced or agronomically knowledgeable enough to develop site-specific management plans on their own. Consequently, many of them purchase prescription maps from professional crop management consultants. However, it is not immediately clear that use of prescription maps made by consultants do indeed increase farm profits. To measure the profit difference, it would be necessary for farmers to know how much they make using their consultants' prescription maps and how much they would have made without the prescriptions. The objective of this study is to demonstrate a method of making that judgement using randomized field trials, followed by regression analysis and the economic assessment of the two scenarios.

Chapter 2: Nitrogen Fertilizer Management

Nitrogen application is one of the most difficult decisions farmers need to make and is affected by many factors, including residual soil nitrogen, rainfall, and temperature

(Stanford, 1982). Nitrogen in the soil can also be lost to runoff, leaching, and volatilization (Scharf, 2015). This makes it difficult for farmers and consultants to predict ahead of time optimal (profit maximizing) site-specific nitrogen application rates. Various variable-rate application methods have been conducted in reference to different data sources, including grid-based soil sampling (Koch et al., 2004) and soil electro-conductivity (EC) measurement (Johnson et al., 2003). Soil EC is a measurement which correlates with soil properties that affect crop production. These properties include soil texture, drainage, cation-exchange capacity, and subsoil characteristics. EC data provides more soil measurements in a shorter amount of time and is more cost-efficient than soil sampling (Grisso et al., 2005). Variable rate seeding has been evaluated using agronomic and economic rules with information on site-specific yield potential (Lowenberg-Deboer, 1990) along with management zones based on soil EC (Ping et al., 2008).

Despite the widespread practice of variable rate input application, methods used to produce site-specific application rate prescriptions vary tremendously. Moreover, these methods are often a "black box". Each model is different, and both companies and consultants are hesitant to release information on how prescriptions are made. Via a series of interviews with farmers and consultants, Bullock found that variable rate prescriptions are often made using information on yield history to divide the field into "management zones (Schrag, personal communication, 2018)." The Environmental Defense Fund (2017) published a series of studies on commercial methods of producing variable rate input application prescriptions. They tested the use of Yara International's *Adapt-N* software for generating site-specific prescription maps and found that the package's recommended input use rates were generally lower than economically optimal rates. They also found that the uniform rate a farmer would apply without getting advice was more profitable than using consultants' recommendations. Similarly, the EDF (2018) tested Climate Corp's *FieldView*® N fertilizer recommendation system and found its recommendations would have increased profits in only 37 of 72 fields during the 2016 and 2017 growing seasons. The *Adapt-N* model and Climate Corp recommendations are two of the most popular nitrogen recommendation software packages. The EDF concluded that *Adapt-N* was never profitable and *FieldView* was only profitable in 51.4% of the examined cases. Now, in addition to questions about the profitability of their consultants' recommendation maps, farmers also have to pay for the consultant to create the prescriptions. Prices vary greatly between agencies, but normally cost around $10 per acre (Bahr, personal communication, 2018; Benisch, personal communication, 2018; Schrag, personal communication, 2018). In order to judge whether the use of consultants' prescription maps increase farm profits, they first need to understand how much more (or less) their consultants' prescription profited farmers compared to what the farmers would have profited without the consultants' prescription maps. Only then could farmers determine if they should be using the consultants' prescription maps. The focus of this study is to provide a method to answer this question by comparing the benefits (or losses) to farmers of following consultants' prescription maps or instead maintaining their status quo management practices.

In this study, we conduct regression analysis on data from a randomized whole-farm experiment data to evaluate the profitability of consultant's site-specific input application prescription map. Specifically, for each of the management zone generated by the consultant we estimate the maize yield response with respect to nitrogen and seed rates. We then use the estimated production functions for both seed and nitrogen to compare the values and the economic returns from following the predicted economically optimal rates (EONRs) and the consultant's recommended rates. This method can be applied to prescription maps from any consultants and gives insight on how variable rate prescriptions can be assessed regardless of the service that is used to create them. The analysis requires the least amount of data necessary: as-applied seed, as applied-nitrogen, yield, and consultant maps. This is beneficial to future researchers focusing on the subject of variable rate technology, consultants that make variable rate application prescriptions, extension agents focusing on VRT, and farmers that use the technology because it offers modeling techniques which can be applied to any variable rate prescription with minimal data to collect.

Chapter 3: Literature Review

Before the advent of precision technology, fertilizer was often applied in uniform rates throughout individual fields (Sawyer, 1994). In past studies, measurements of nitrogen use efficiency (NUE) have often shown that low NUE occurs when nitrogen is not in the correct form for crop uptake, uniform application rates are applied to a field, and temporal variables such as rainfall are not taken into account (Shanahan et al., (2008). The group estimates that $28 billion is lost per year due to low NUE. Raising NUE through VRT could have a large effect on the farm profitability. In order for variable rate models to be effective, they must increase NUE.

When nitrogen fertilizer is applied sight-specifically, first soil data is usually taken, either in the by soil sampling or measurement of soil EC. In terms of soil sampling, grid-based sampling is often used. Grid-based sampling is very pricey and the optimal spacing between samples is debatable. Hammond (1993) found that a 197-foot grid was better than 98 and 394-foot grids. Franzen and Peck (1995) found that a 212-foot grid was adequate compared to a grid of 81 feet.

In addition to using soil sampling and soil EC, many researchers have tried to apply site-specific management zones (SSMZ) in an attempt to lower the input cost to apply variable rate nitrogen. Doerge (1999) defines a management zone "a sub-region of a field that expresses a relatively homogeneous combination of yield-limiting factors for which a single rate of a s specific crop input is appropriate." Past studies have focused on delineating management zones through yield history, soil color, topography, and management experience (Koch et al., 2004) or bulk density, cone index, surface soil color, organic Carbon, texture, sorptivity, and surface water (Mzuku et al., 2005) or soil EC (Fleming et al., 2000). SSMZs are often used by consultants and they need to be evaluated individually to determine if the consultant's results are profitable.

The results of past research on variable rate seeding has been mixed. In one case, variable rate seeding of corn was found to profit $12.83 to $0.15 per hectare depending on the amount of information the farmer had (Bullock et al., 1998). In another study, Lowenberg-DeBoer (1999) found that although farmers are better off using a uniform seeding rate when they have a mix of medium and high potential land, variable rate seeding could become profitable if 10% of the farm has low yield potential soil. Variable rate technology is relatively new and is not being widely adopted. Significant investment is required, and payoffs are uncertain (McBride & Daberkow, 2003). Growth of VRT use has been primarily driven by agents in the private sector such as crop consultants or input suppliers. Although higher NUE is possible with precision tools there is a steep learning curve, farmers with a higher level of education and farm size tend to adopt precision technologies in higher numbers (Adrian, Norwood, & Mask, 2005). In order for variable rate technology to become widely accepted more studies need to have significant results.

In a series of interviews with scientists, consultants, and growers, Bullock found some useful insights on the current state of VRT. The suppliers of variable rate application prescriptions are split into three groups: consultants who use plans they created on their own (Allen et al., personal communication, 2018), consultants who act as a middle-man and use a third-party platform to create recommendations (Schrag, personal communication, 2018), and consultants who work for large companies such as Corteva AgriScience or Bayer Crop Science and use that corresponding company's platform to create recommendations (Brown, personal communication, 2018).

Generally, consultants use grid sampling, yield history, and yield goals in order to make recommendations. Soil sampling is normally done on a 2.5-acre grid every three to four years (Benisch, personal communication, 2018; Naysmith & Herbel, personal communication, 2018; Schrag, personal communication, 2018). These soil samples are great for making fertilizer recommendations on potassium, phosphorous, and lime on fields; however, they are only beneficial for nitrogen application on the year they are taken due to uncertainty in nitrogen movement within the soil and the numerous variables that affect it (Naysmith & Herbel, personal communication, 2018). Some consultants support their recommendations through additional methods including soil EC (Lofing, personal communcication, 2018), soil moisture and temperature readings (Grote, personal communication, 2018), aerial imagery (Houin, personal communication, 2018), and weather data (Beetz, personal communication, 2018). Yield history is used to divide the field into site specific management zones (Schrag, personal communication, 2018). Producer yield goals are then typically multiplied by 1.2 to leave room for error when application decisions are made (Mayeske, personal communication, 2018).

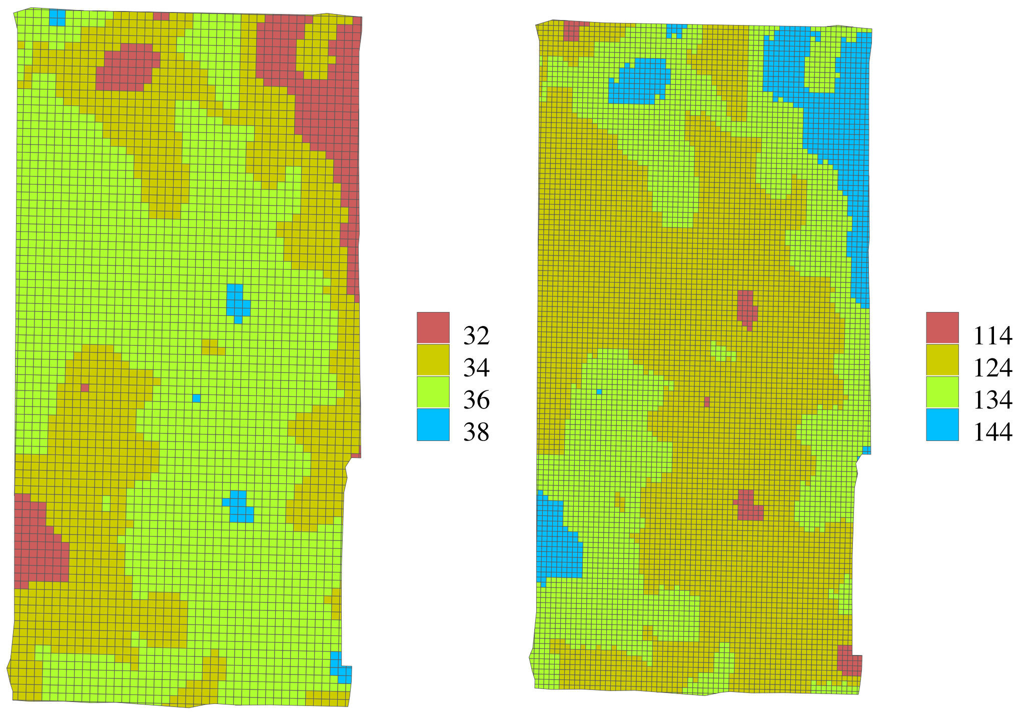
Nitrogen and seeding rates are then prescribed to each zone in order to hit the boosted yield goal. Consultants claimed that recommendations are normally very conservative (Schrag, personal communication, 2018). Due to the volatility in the nitrogen cycle they feel it is better to over apply nitrogen and be conservative when making recommendations. This could hinder profitability but mitigates risk for both the consultant and the farmer.

Farmer's views on variable rate technology seem to differ depending on age. Bradford claimed that he sees a lot of younger farmers that will be transitioning to the owner of the family farm getting involved with variable rate technology (personal communication, 2018). Transparency is also an issue as many farmers do not want large companies to have the data for their farm. They feel that the companies can use this to their advantage (Phelps, personal communication, 2018). Some simply believe that the technology is profitable without needing proof, but others feel like it is hard to determine whether using variable rate technology is profitable (Brown, personal communication, 2018). Many of the farmers that were interviewed put in test blocks or strip trials but claim that they need more statistical background in order to make decisions (Martz, personal communication, 2018; Norris, personal communication, 2018).

Nutrient Star, a company ran by the Environmental Defense Fund (EDF), scientifically reviews nutrient management tools using regression modeling. The EDF assesses NUE which is measured as unit of yield over unit of applied nutrient in order to lower input costs and environmental impact. The group recognizes production goals and takes them into account during their studies. The models they use are linear and quadratic models of nitrogen on yield. They then evaluate the model and use the model with the best fit R^2 to determine yield at the farmers rate, model rate, and the economically optimum rate.

When looking at the Adapt-N model, the Environmental Defense Fund (2017, 2018) found that model was much lower than the economically optimum rate and the farmer rate. The farmer's nitrogen strategy was much closer to the economically optimum rate than the model's estimation. On two separate years, the Environmental Defense fund (2018) evaluated Climate Corporations Nitrogen Model using the same method. In 2016, the Climate Corporation's Model was more profitable on 12 out 34 trials. However, it had very large returns on the areas of the field in which less than 100 lb/acre was needed showing that many farmers over applied in these areas. In 2018 the studies showed that the Climate Corporation's model was profitable in 25 out of 38 trials. It showed negative returns from using the model where the highest yielding rates were below 100 lb/acre or above 250 lb/acre. Areas of the field where the agronomic optimum rate fell between 100-250 lb/acre made an average of $17 per acre more than the farmer's recommendation.

Chapter 4: Consultants Prescription Map



(a) Seed Rate (1000/acre) (b) Nitrogen Rate (lb/acre)

Figure 1: Consultants Recommended Seed and Nitrogen Application Rates

The seeding and nitrogen prescription rates from the consultant are shown in Figure 1. These maps are almost identical in their spatial delineations. The consultant basically created four management zones, each of which is assigned a unique seed-N rates combination. Table 1 presents the four zones. It suggests that high target seed rates are placed with low nitrogen rates. The strategy of putting more fertilizer in the less fertile zones was explored by Delgado et al. (2005). They created a field study which utilized a recommendation based on soil samples, and two recommendations in which site-specific management zones applied both higher rates and lower rates in more productive zones. They showed that putting lower amounts of fertilizer in high productivity zones is less productive than putting on a more nitrogen in highly productive zones showing that the consultant's strategy may not be the best application of nitrogen.

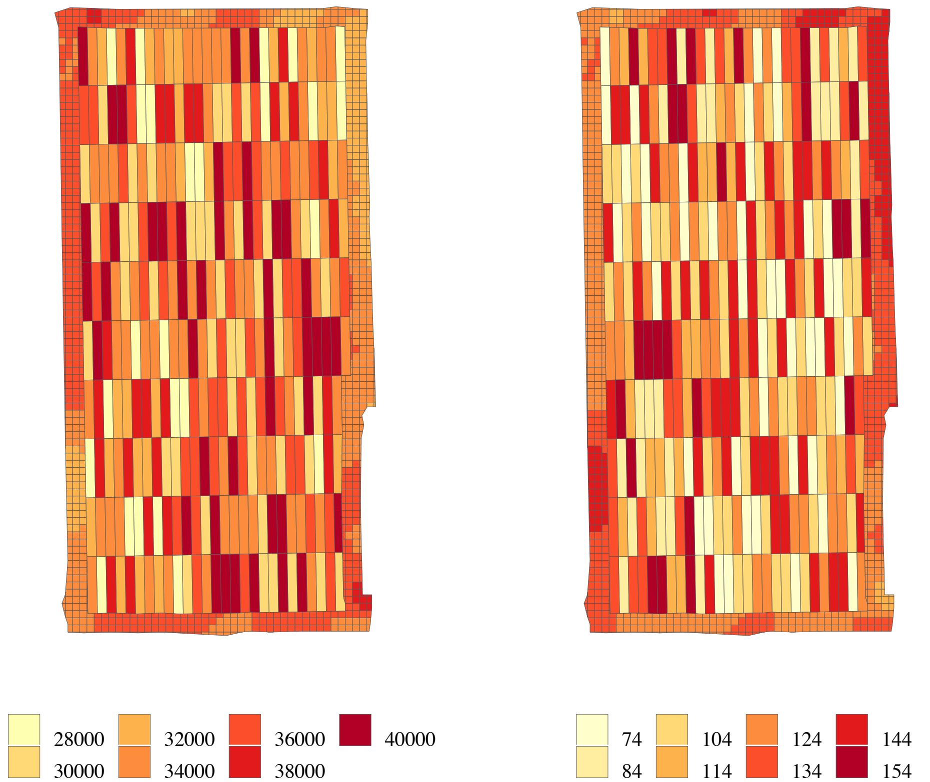
Zone	Nitrogen (lb/acre)	Seeds (1000/acre)
1	144	32
2	134	34
3	124	36
4	114	38

Table 1: Four Management Zones Generated by Consultant

Chapter 5: Trial Design

The consultant's recommendations were used to design the randomized whole-field trial on a 76-acre field, located in Crawford County Ohio. The experiment design is based on the prescription maps from the consultant. Zones 1 and 4 are much smaller in size compared to zones 2 and 3, as can be seen in Figure 1. It is practically impossible to have enough replications for each of zones 1 and 4. Thus, to simplify the trial design, zones 1 and 2 were combined (hereafter, denoted as zone A) in designing the field trial. Similarly zones 3 and 4 were combined (hereafter, zone B) for the same purpose. Zone A randomized nitrogen rates among 84, 114, 134, and 154 lb/acre of NH_3, and randomized seeding rates amount 28,000, 32,000, 34,000, and 38,000 seeds per acre. Zone B randomized nitrogen application between 74, 104, 124, and 144 lb/acre of NH_3 and randomized seeding rates between 30,000, 34,000, 36,000, and 40,000 seeds per acre. Experimental plots are forty feet wide to account for the farmer's combine and used a 80-

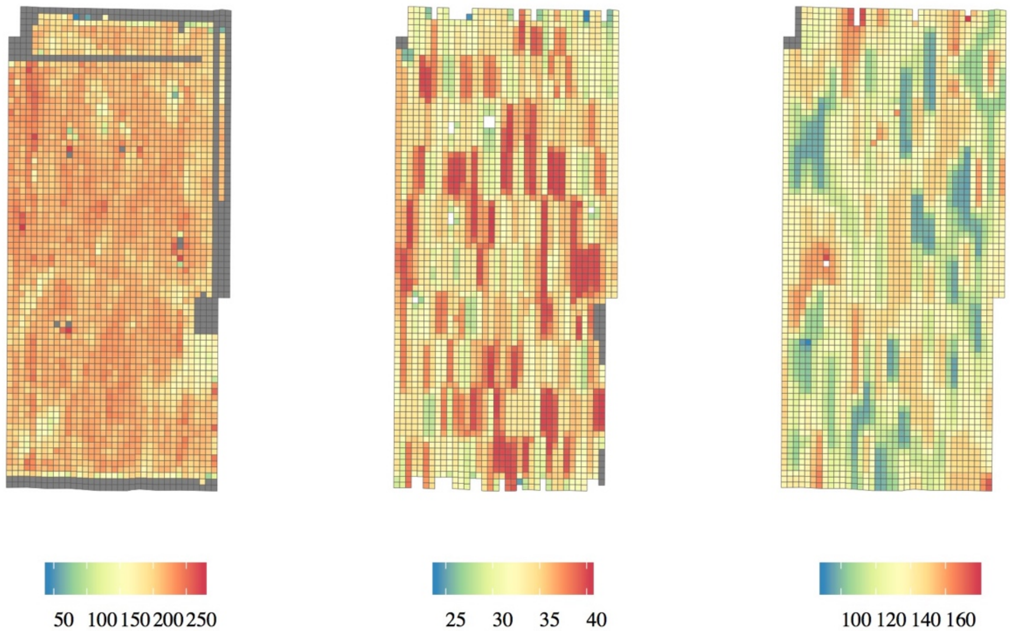
feet buffer around the edge of the field. The resulting trial design is depicted in in Figure 2.



(a) Seed Rate (1000/acre) (b) Nitrogen Rate (lb/acre)

Figure 2: Trial Design of Seed and Nitrogen Rates

Chapter 6: Data and Preliminary Observations



(a) Yield (bu/acre) (b) Seed Rate (1000/acre) (c) Nitrogen Rate (lb/acre)

Figure 3: The Spatial Distribution of Yield, As-applied Seed Rates, and As-applied Nitrogen Rates

From the field trial, we obtained data on as-planted seed rates, as-applied nitrogen rates, and yield. Those data were cleaned and processed as described in Bullock, et al (2019). The spatial distribution of yield, as-applied seed rates, and as-applied nitrogen rates are shown in Figure 3. Interestingly, there is very little spatial heterogeneity in yield across the entire field despite the fact that seeding, and nitrogen rates were greatly varied.

Statistic	N	Mean	St. Dev.	Min	Max
Yield (bu/acre)	2,073	212.14	20.22	69.30	274.43
As-applied Seed Rate (1000/acre)	2,234	34.83	3.03	26.90	40.34
As-applied Nitrogen Rate (lb/acre)	2,249	130.17	17.32	90.09	178.21

Note: This is the summary statistics of the field trial data conducted.

Table 2: Summary Statistics of The Field Trial Data

It can be seen in Table 2 that plots had a much wider range of applied nitrogen and seed compared to the consultant's recommendations. It is important to note that yield is measured in bushels per acre, nitrogen is measured in units of NH_3 per acre, and as applied seeding rate is measured in number of 1000 seeds per acre. While the causal impacts of nitrogen and seed rates on yield will be discussed with our regression analysis, looking at their correlations with yield are insightful. The correlation coefficients between the variables presented in Table 3 offer interesting insights into the data. As-applied nitrogen has a very low positive correlation with yield, which hints that applying nitrogen to this field did not have much of an effect on yield; however, as-applied seed rate's correlation coefficient of .25 does indicate a positive impact.

	Yield	As-applied Seed	As-applied Nitrogen
Yield	1.00	0.25	0.02
As-applied Seed	0.25	1.00	-0.06
As-applied Nitrogen	0.02	-0.06	1.00

Table 3: Correlation Coefficient Matrix of Key Variables

The soil map from the USDA Web Soil Survey is shown in Figure 4, with a key showing the locations of the field's soil types and the predicted bu/acre when non-irrigated corn is planted. As expected from the yield maps, the soil profiles change, but expected yield is relatively consistent. The yields are much lower than the yields in our study; however, the variation in yield potential is what is important to this paper. Table 4 shows that 6.9% of the field has a yield potential very close to 120 bushels while 14.7% of the field has a yield potential of 101.2 bu/acre. The yield potential determined by the Web Soil Survey is based on average yield from previous years. Only 8.4% of the field has a yield potential of 160 bu/acre. Even though the soil types change a lot in this field, they all have a similar potential to produce yield. This implies that there might a little gain in managing input use site-specifically for this field as yield potential is a major factor in determining application (Meisinger, Schepers, & Raun, 2008).

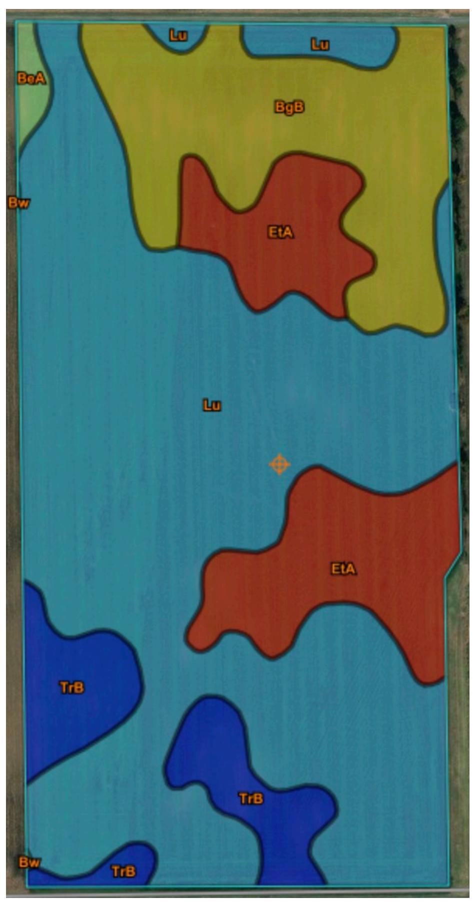


Figure 4: Soil Type of the Field from the Web Soil Survey

Map Unit	Map Unit Name	Slope	Yield Rating (Bu/Acre)	Acres	Percent of Field
BeA	Bennington Silt Loam	0-2%	119.5	0.7	0.90%
BgB	Bennington Silt Loam	2-6%	115.45	12.6	16.60%
EtA	Elliot Silt Loam	0-3%	101.2	11.1	14.70%
Lu	Luray Silty Clay Loam		125	45.1	59.40%
TrB	Tiro Silt Loam	2-6%	166.22	6.3	8.40%

Table 4: Web Soil Survey Data of the Field

Table 5 shows the number of observations for each zone. It is clear that no statistical analysis will be reliable for zone 4. Thus, we will remove the zone from any of our subsequent analysis. Zone 1 has also a small number of observations. While we do not remove zone 1, we will not place much emphasis on the results for the zone because it is likely that statistical analysis of the zone is likely to suffer from inaccuracy.

zone	Number of Observations
Zone 1	72
Zone 2	564
Zone 3	1427
Zone 4	6

Table 5: Number of Observations by Management Zone

Chapter 7: Methods

The main goal of the study is to evaluate the profitability of prescription maps created by a consultant. In order to achieve this goal, we will take the following steps: (1) estimate the production function with respect to seed and nitrogen rates for each of the management zones defined by the consultant, (2) estimate the profit-maximizing rate of seed and nitrogen rates for each management zone, (3) estimate the profit for each management zone that would have been made for two cases: the economically optimal rates and the consultant's recommended rates, and (4) evaluate the consultant's recommendation by contrasting its profitability against the maximum profit the farmer could have made.

7.1: Econometric Methods

We estimate a crop production function for each of the three management zones developed by the consultant. All the management zones shared the same econometric model:

$$Y = \beta_0 + \beta_1 S + \beta_2 S^2 + \beta_3 N + \beta_4 N^2 + \varepsilon$$

The dependent variable Y is yield. The independent variables include seed (S) and nitrogen (N) rates. Quadratic functional forms were used for both seed and nitrogen rates because both of them can have a nonlinear effect on yield as shown in (Shrader, Fuller, & Cady, 1966) and the response of yield on seeding rate (Bullock et al. 1998). Finally, ε is the error term. It is worth mentioning that we do not have to be concerned about the endogeneity of nitrogen and seed rates as they are randomized.

7.2: Maximum Attainable and Consultant's Profit

In order to estimate the maximum profit attainable, we first found the profit maximizing seed and nitrogen rates for each zone. If $\hat{f}_z(S,N)$ denotes the estimated production function for management zone z. Then, the following maximization problem was solved:

$$Max_{S,N} \quad P_C \times \hat{f}_z(S,N) - P_S \times S - P_N \times N \text{ - } 600$$

where P_C, P_S, and P_N was the price of corn, seed, and nitrogen, respectively. Six hundred is subtracted from the maximization problem to account for other costs. We solved the above maximization problem for all the zones. After this process, we simply plugged in the estimated optimal seed and nitrogen rates back to the objective function to find the estimated maximum profit attainable for each zone. We found the profit the farmer would have made if the consultant's recommended rates were followed, we plugged in their recommended rates into the objective function and found the profit. Throughout this analysis, the price of corn (P_C), seed (P_S), and nitrogen (P_N) was assumed to be \$3.5/bu, \$3.2/1000 seeds, and \$0.4/lb.

Chapter 8: Results and Discussions

8.1: Regression and Economic Optimization Results

	Dependent Variable: Yield (bu/acre)	
	34-134 (Zone 2)	36-124 (Zone 3)
Seed	23.688***	7.814*
	(6.425)	(3.240)
Seed squared	−0.335***	−0.093*
	(0.096)	(0.046)
Nitrogen	−1.012	−0.635
	(0.799)	(0.420)
Nitrogen squared	0.004	0.003
	(0.003)	(0.002)
Constant	−146.531	89.197
	(120.399)	(63.853)
Observations	564	1,427
Adjusted R^2	0.044	0.054
Note:	*p<0.05; **p<0.01; ***p<0.001	

Table 6: Regression Results

Table 6 presents the regression results for zones 2 and 3. Neither seed rate nor nitrogen rate is statistically significant for zone 1. This is likely because of the small number of observations for the zone. Hereafter, we will not present the results for any of subsequent economic analysis, as we cannot simply rely on the regression results for the zone. For management zones 2 and 3, the seed rate and its squared term are both statistically significant. However, interestingly, the nitrogen variables are not statistically significant for either management zone 2 or 3. This means that seed rates affect yield, but nitrogen rates do not. We conclude that nitrogen application at rates higher than the lowest experimental rate (90 lb/acre) would simply cost the farmer without increasing revenue. On the other hand, increasing the seed rate enhances profit until a certain point, and then damages profit afterward because the cost of a marginal increase in seed outweighs the cost of marginal increase in revenue. Figure 5 shows how profit changes as seed rate is increase for each of management zones 2 and 3. Profit-maximizing seed rates are 33,950 and 37,000 seeds per acre for management zones 2 and 3. Figure 6 presents our estimated optimal seed rate prescription map for zones 2 and 3.

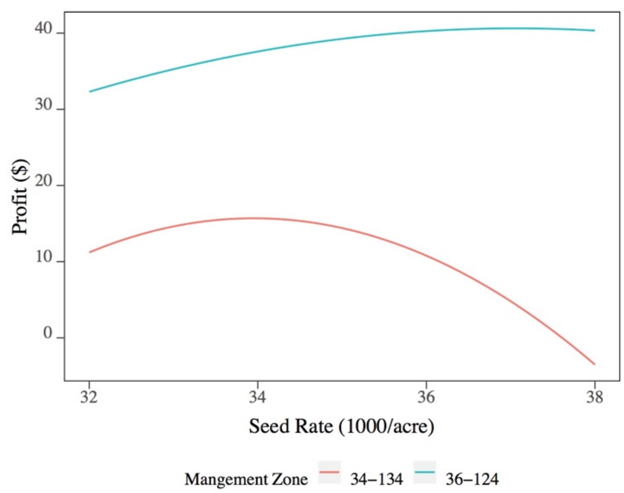


Figure 5: Profit Curve with Respect to Seed Rate

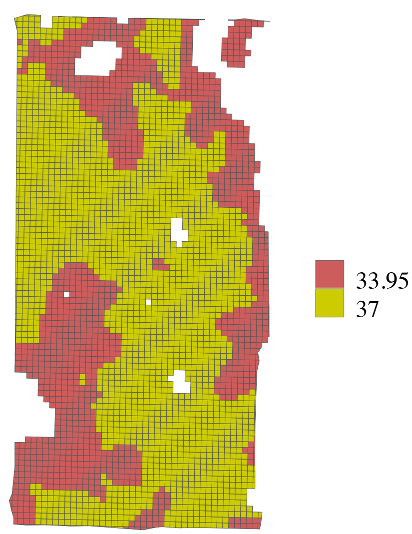


Figure 6: Site-specific Optimal Seed Rates

8.2: Optimal vs Consultant's Recommendation

The consultant recommended 34,000 and 36,000 for management zones 2 and 3. Thus, while the consultant would have under-applied seed for zone 3, he was almost right on for management zone 2. The consultant would have cost the farmer almost nothing for management zone 2, but $3.20 per acre for management zone 3. The main cause of the loss in profit using the consultant's recommendations is the over-application of nitrogen. The statistical insignificance of nitrogen variables indicates that the lower the nitrogen rate, the more profitable, at least within the range of nitrogen rate tested in the experiment. Since we should not extrapolate to predict what would have happened to yield if we were to apply a nitrogen rate lower than 90 lb/acre, we set 90 lb/acre as the optimal nitrogen rate for this field. For zones 2 and 3, additional nitrogen beyond 90 lb/acre is a pure waste of money. The consultant failed to recognize the real impact of nitrogen and recommended much higher nitrogen application rates for all the zones. The farmer lost 11.15 and 7.87 per acre for zones 2 and 3, respectively. Figure 7 presents economic loss of using consultant's recommendation relative to the highest the farmer could have earned. Overall, the consultant would have costed about $11/acre for the majority of the field.

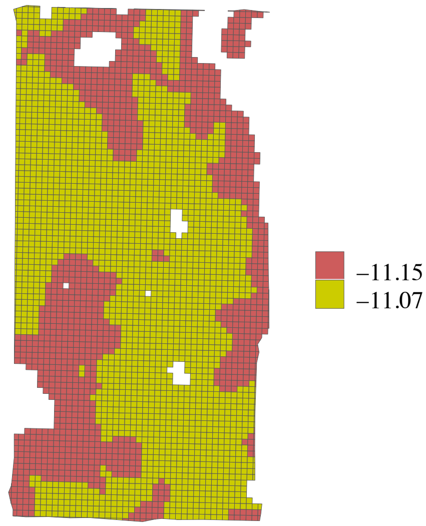


Figure 7: Economic Loss of Following the Consultants' Recommended Rates by Management Zone

Chapter 9: Conclusion

We have proposed a method of analyzing on-farm field experimentation data to estimate the profitability of site-specific management prescriptions. While numerous companies and consultants sell site-specific prescription maps to farmers, their methods are questionable. Consultants often do not understand the modeling techniques and the models in particular are not viewable by researchers. More importantly, it is difficult to know if farmers are earning more money by utilizing such services. This study presented a framework to answer whether farmers are paying money to create less profit.

Our results suggest that it is not advisable to blindly believe the prescriptions made by consultants. Our results also speak of the potential power of on-farm randomized field trial. The largest loss in profit does not come from the failure to recognize the spatial variability of the need for nitrogen. Rather, it was an over-application of nitrogen almost everywhere across the field. The on-farm field trial allows farmers to notice the error in nitrogen application.

Especially for rainfed production, yield response to nitrogen and seed can vary dramatically with weather year to year. Our results are based on data from a single year's experiment, which limits the inferences that can be drawn. This means the over-applied nitrogen rates in this study could have been a result of weather. If we were to conduct another experiment on a different year, the results could have been different. Nonetheless, the method we have presented of verifying the profitability of recommendation maps (whether they are made by farmers themselves or their consultants) should be valuable to practitioners including farmers, consultants, extension agents, and researchers. This method should be used more expansively in the future and applied to various models in order to make an educate conclusion on the current profitability of variable rate application.

References

Adrian, A. M., Norwood, S. H., and Mask, P. L. (2005). Producers' Perceptions and Attitudes Toward Precision Agriculture Technologies. *Computers and Electronics in Agriculture*, 48(3):256– 271.

Allen, D., Ikins, G., Fisher, G., and Bradford, J. Interview. Conducted by David Bullock, 2018.

Bullock, D. G., Bullock, D. S., Nafziger, E. D., Doerge, T. A., Paszkiewicz, S. R., Carter, P. R., and Peterson, T. A. (1998). Does Variable Rate Seeding of Corn Pay? *Agronomy Journal*, 90(6):830– 836.

Bullock, D., Boerngen, M., Tao, H., Maxwell, B., Luck, J., Puntel., L., and Martin, Nicolas. (2019).The Data-Intensive Farm Management Project: Changing Agronomic Research Through On-farm Precision Experimentation. Manuscript submitted for publication.

Delgado, J., Khosla, R., Bausch, W., Westfall, D., and Inman, D. (2005). Nitrogen Fertilizer Management Based on Site-specific Management Zones Reduces Potential for Nitrate Leaching. *Journal of Soil and Water Conservation*, 60(6):402–410.

Doerge, T. (1999). Defining Management Zones for Precision Farming. *Crop Insights*, 8(21):1–5.

Environmental Defense Fund. "Adapt-N Research Findings: Reports Associated with Summary Trial Data." 2018. Retrieved from Nutrient Star, Environmental Defense Fund website: http://nutrientstar.org/files/2018/03/Climate-Corp-2016-field-by-field-results-Ecker-3-15-2018.pdf.

Environmental Defense Fund. "FieldView™ Research Findings: Reports Associated with Summary Trial Data." 2018. Retrieved from Nutrient Star, Environmental Defense Fund website: http://nutrientstar.org/files/2018/09/Climate-Corp-2017-field-by-field-results-Ecker-9-15-2018.pdf.

Environmental Defense Fund. "Report – Analysis of 2016 Adapt-N Yields." 2017. Retrieved from Nutrient Star, Environmental Defense Fund website: http://nutrientstar.org/files/2017/12/NutrientStar-Adapt-N-report-2016-data.pdf.

Fleming, K., Westfall, D., Bausch, W., et al. (2000). Evaluating Management Zone Technology and Grid Soil Sampling for Variable Rate Nitrogen Application. In *Proceedings of the 5th International Conference on Precision Agriculture*, pages 16–19. ASA, CSSA, and SSSA Madison, Wisc.

Franzen, D. W. and Peck, T. R. (1995). Field Soil Sampling Density for Variable Rate Fertilization. *Journal of Production Agriculture*, 8(4):568–574.

Grisso, R. D., Alley, M. M., Holshouser, D. L., and Thomason, W. E. (2005). Precision Farming Tools. Soil Electrical Conductivity.

Hammond, M. W. (1993). Cost Analysis of Variable Fertility Management of Phosphorus and Potassium for Potato Production in Central Washington. In *Proceedings of Soil Specific Crop Management*, number proceedingsofso, pages 213–228. American Society of Agronomy, Crop Science Society of America, Soil Science.

Johnson, C. K., Mortensen, D. A., Wienhold, B. J., Shanahan, J. F., & Doran, J. W. (2003). Site-specific Management Zones Based on Soil Electrical Conductivity in Semiarid Cropping System. *Agronomy journal*, *95*(2), 303-315.

Koch, B., Khosla, R., Frasier, W., Westfall, D., and Inman, D. (2004). Economic Feasibility of Variable-rate Nitrogen Application Utilizing Site-Specific Management Zones. *Agronomy Journal*, 96(6):1572–1580.

Lowenberg-DeBoer, J. (1999). *Economics of Variable Rate Planting for Corn*. Number precisiona- gric4b. American Society of Agronomy, Crop Science Society of America, Soil Science.

McBride, W. D. and Daberkow, S. G. (2003). Information and the Adoption of Precision Farming Technologies. *Journal of Agribusiness*, 21(345-2016-15210):21–38.

Meisinger, J. J., Schepers, J. S., & Raun, W. R. (2008). Crop Nitrogen Requirement and Fertilization. *Nitrogen in Agricultural Systems*, (nitrogeninagric), 563-612.

Scharf, P. C. (2015). Managing Nitrogen. *Managing Nitrogen in Crop Production*, (managingnitroge2), 25-76.

Stanford, G. (1982). Assessment of Nitrogen Availability. *Nitrogen in Agricultural Soils*, (nitrogeninagrics), 651-688.