Impact of uncertainty on selecting manure application rates: The science of manure mystery

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Abstract

Selecting appropriate fertilization rates is critical for optimizing crop yield and protecting the environment. Optimal nitrogen fertilizer rates are typically calculated assuming average growing conditions and assuming “perfect” information. In practice, uncertainty about critical impact variables adds risk to fertilization decisions. We evaluate how the uncertainty of different process variables (crop nitrogen response, manure nitrogen content, application rate, nutrient content variability, manure nitrogen availability, volatilization losses, and application uniformity) impact the optimal application strategy. This work demonstrates that the economic optimum nitrogen fertilization rate increases when accounting for uncertainty in different variables. More specifically, we show that higher uncertainty in any term causes the optimum economic rate to increase proportionally. While much attention has been given to providing farmers with tools and methods to select appropriate rates, just as important is providing them with the confidence and technology to trust their choice and equipment. Moreover, using the concept of uncertainty, we demonstrate why split fertilizer application only has limited potential to improve nitrogen management. When used as a tool to manage risk and uncertainty, its benefits have traditionally been underestimated.

Introduction

Agriculture faces numerous challenges: volatile commodity prices, increased land and fertilizer prices, and the most critical environmental challenges of sustainable soil and water quality. Specifically, increasing the input of nutrients (N, P) has played a crucial role in maximizing agricultural productivity. The nutrients are essential for crop growth and, in most cases, among the critical yield-limiting variables. However, while their use has supported high yields, it has also led to increased transport and water loss. Ameliorating agricultural production’s negative environmental impacts is increasingly important on a planet of finite size and an increasing human population. Two ecological impacts of particular concern are the use and subsequent loss of macronutrients such as nitrogen (N) and phosphorus (P) (Tilman et al., 2001). Nutrient use efficiency is especially pertinent in livestock production, where manure’s duality, as waste or resource, is a matter of perception and choices. Recycling manure by land-applying it to crop production areas provides an opportunity to close the nutrient cycle. In so doing, the dependence on synthetic and mined fertilizers decreases, farm sustainability improves, and expenses for commercial fertilizers are reduced (Honeyman, 1996).

Manure can serve as an excellent fertilizer source, providing all three major crop nutrients (nitrogen, phosphorus, potassium) and many micronutrients (sulfur, copper, iron, manganese, zinc). Moreover, manure provides organic matter to the soil as it is applied, increasing soil carbon and improving soil structure. While there are numerous benefits of land application of manures, there are also innumerable impediments limiting its use or making it more challenging to incorporate into cropping systems. These include high transportation and handling costs, odors, compaction, and perhaps most of all, uncertainties and variabilities with application rate, nutrient content, nutrient availability, volatilization, timing, and uniformity across the spread pattern. Together, these uncertainties in the number of nutrients add substantially to the difficulty of making sound agronomic and environmental decisions when it comes to selecting manure application rates.

This study aims to quantify the impact various uncertainties have on selecting nitrogen application rates and, in particular, the economic optimum nitrogen application for livestock manured fields. We will quantify uncertainty components from existing literature related to nutrient content, variability during removal, availability, volatilization, application uniformity, and volumetric application rate and assess the impact on manure fertility confidence. In this study, a general model of N rate decision-making under uncertainty is presented, and a sensitivity analysis is performed to measure the influence of each model parameter. The objectives are to assess what aspects make a system particularly vulnerable to inefficiencies from uncertainty and therefore particularly suited to investments that would reduce these uncertainties. Finally, we use these processes to investigate how altered management strategies, such as split nitrogen application and the reduction in fertilization process uncertainty, change recommendation guidelines.

Materials and methods

Understanding the variability of nutrient content, especially nitrogen if used to set the application rate, is critical for understanding manure fertilization decisions. Moreover, knowledge of how different uncertainties in the fertilization process contribute to nitrogen application is paramount for determining where to invest resources to reduce the uncertainty. I constructed a static, spreadsheet-based model to account for the process variables involved in manure fertility decisions and assessed how different sources of uncertainty or application error impacted the value manure offered in the fertility program.

For each variable, I assumed a normally distributed random variable, defined by its mean (m) and standard deviation (σ). The ideal manure application rate was determined based on the average values for each of the process variables. Then a Monte Carlo simulation of 1000 draws from the random distributions performed to determine the fertility supplied by the manure and how that differed from the actual fertility value in terms of negative economic impact. The economic impact was calculated as either from reduced yield from supplying less nitrogen than anticipated or through the cost of excess nitrogen provided.

Results

How does uncertainty impact the manure nitrogen application rate you select?

Selecting an appropriate nitrogen fertilizer rate is critical for optimizing profit from cornfields. Applying too little N reduces profit by reducing grain yield; too much N and you don’t get a return on the nitrogen you bought and can cause damage to the environment. In Iowa, most manure management plans are filled out using the yield goal method, with current university guidelines suggesting the use of the maximum return to nitrogen approach. If you are a long-time reader of this blog, you’ve probably seen both of these discussed before, so don’t worry, that isn’t the topic today, instead, I’m focusing on uncertainties in the application and what that means for how we make decisions.

A lot of uncertainties exist when using manure as a fertilizer. Some examples include:

- Nitrogen need of the crop (every growing season is a bit different)
- Spatial variation in nitrogen need to support crop production (because all soils aren’t the same)
- Nutrient content of the manure
- Nutrient variation from start to finish of manure application
- Application Rate control and Variation in Application Rate
- Availability of the manure nitrogen to the crop
- Amount of nitrogen lost to volatilization
- Non-uniformity in application rate

For now, I want to just look at that manure application parts of this uncertainty, and assume we know perfectly the crop response to nitrogen. How does all the variation and uncertainty impact the nitrogen application rate we should select? To answer this question, I first parameterized the yield response curve from the maximum return to nitrogen. The price of corn was set at $5.65 a bushel and nitrogen price at $0.40 a pound, which in a corn soybean rotation gave an optimal nitrogen rate of 150 lb N/acre.

The manure nitrogen content was set at 40 lbs N/1000 gallon, nitrogen availability at 95%, the nitrogen volatilization coefficient at 98%, and the desired application rate of 3706 gallons/acre calculated. A Monte Carlo simulation was then performed. For each variable that added uncertainty (manure N/ content, Application rate, Volatilization coefficient, Nitrogen availability, and the knife-to-knife coefficient of variation) a normal distribution was constructed using the average value listed above and standard deviations of 2.75, 250, 0.01, & 0.05 respectively and the knife-to-knife variation varied between 0 and 100%. I then performed 3500 simulations drawing randomly from the distributions I just created to determine the nitrogen application rate for each knife (for distributions with natural limits, such as volatilization coefficient no values over 100% were allowed).

A lost value from application variability and uncertainty was calculated. If the actual amount of available N applied was greater than the MRTN rate of 150 lb N/acre, the value was set at the differences between the amount of N applied minus 150 lb N/acre times a nitrogen price of $0.40 a pounds. If the nitrogen application rate was less than the MRTN rate the value was set at the difference between corn yield at MRTN and the projected corn yield at the N rate applied times a corn price of $5.65 a bushel. The average loss in profit for all 400 knife simulations for each of the 3500 simulations was calculated, and then the average and standard deviation of the 3500 simulations calculated.

A maximum return curve was calculated by taking the profit that would have been generated with perfect information (200 bu/acre x $5.65/bu – 150 lb N/acre x $0.40/lb N) minus the profit lost from uncertainty and application variability using the procedure listed above. Here we see an interesting trend – the uncertainty of ammonia volatilization & nitrogen availability, and the variation in volumetric application rate and manure nitrogen content during application make it advisable to apply six pounds more available nitrogen per acre than if we didn't have these variations. This occurs as the economics of nitrogen application is non-symmetrical, with the cost of being a pound short greater than being a pound heavy. Suppose we factor in any knife-to-knife application variability. In that case, the story gets more interesting, with the ideal application rate first increasing (until we reach a knife-to-knife application variability of about 40%, where the ideal rate is 167 pounds of N/acre, or 17 pounds /acre higher than the known nitrogen response curve we put in), and then decreasing to 137 lb available N/acre.

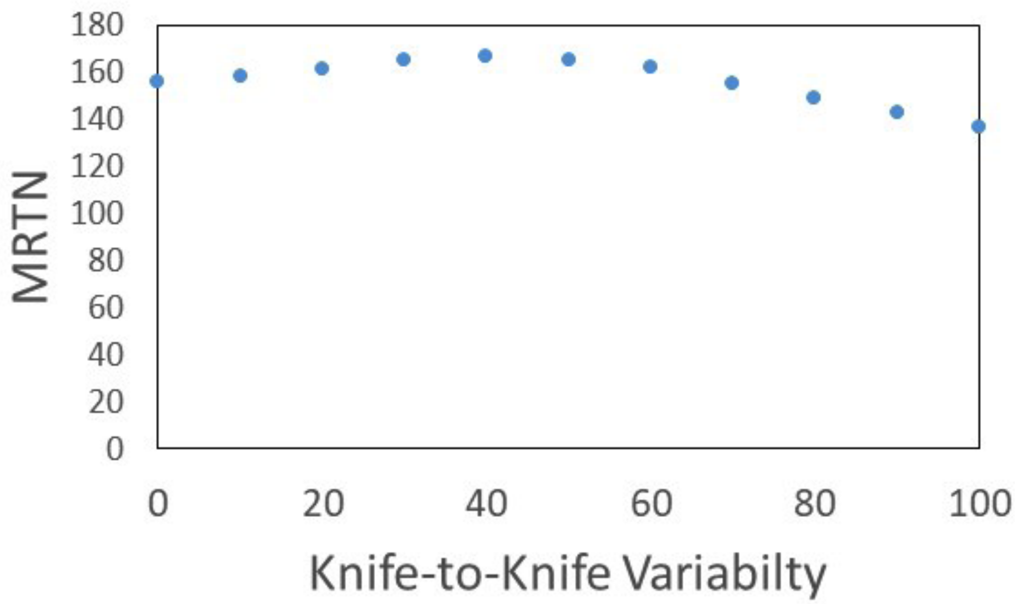

Figure 1. Impact of knife-to-knife variability on the impact of the maximum return to nitrogen for a spring applied swine manure to corn in a corn-soybean rotation. Ideal rate varies with our machinery variation.

But what about a fall application? As the MRTN curve is based off spring nitrogen applications I added a term to the model to account for N-loss from fall to spring. In this cased I assumed an average of 15 lbs N/acre with a standard deviation of 15 lb N/acre and performed the same Monte Carlo simulation as above (but with the available N corrected for estimated nitrogen loss.

Estimating the value of real-time manure nutrient monitoring

The value of real-time manure N content sensing was calculated roughly following the procedure above, except normal distributions of manure N content were generated. The procedure was as follows. Microsoft Excel was used to generate a list of 3500 random numbers between 0 and 1 using the RAND() function. The Norm.inv function was then used to assign the nitrogen content of each manure load using an average nitrogen content, the standard deviation of the nitrogen content, and the random number as inputs. Average N contents used were 19, 30, 42, 53, and 64 kg N/m3 (17, 27, 37, 48, 58 lbs N/1000 gallons). The standard deviation was set at 3.4 kg N/m3 (3.06 lb N/1000 gallons). Average N contents used in the modeling were the average of this data set, the average ± one standard deviation, and the average ± s standard deviations.

Appropriate application rates to supply 168 kg N/ha and 224 kg N/ha for corn in a corn-soybean rotation and corn in a continuous corn rotation were determined. These application rates were applied to the 3500 randomly generated manure loads. If this results in more than the target N rate being applied, the value of real-time N sensing for that load was set to the extra nitrogen applied, \$0.70/kg N (\$0.32/lb N). If nitrogen was under-applied, yield estimates were generated based on the target N rate and the N rate achieved (based on the N-response curves for the main region of Iowa). The yield estimate difference was then multiplied by the value of corn, \$5.52 a bushel, to estimate the value. The value for the real-time manure testing was calculated as the average of the 3500 simulated manure loads.

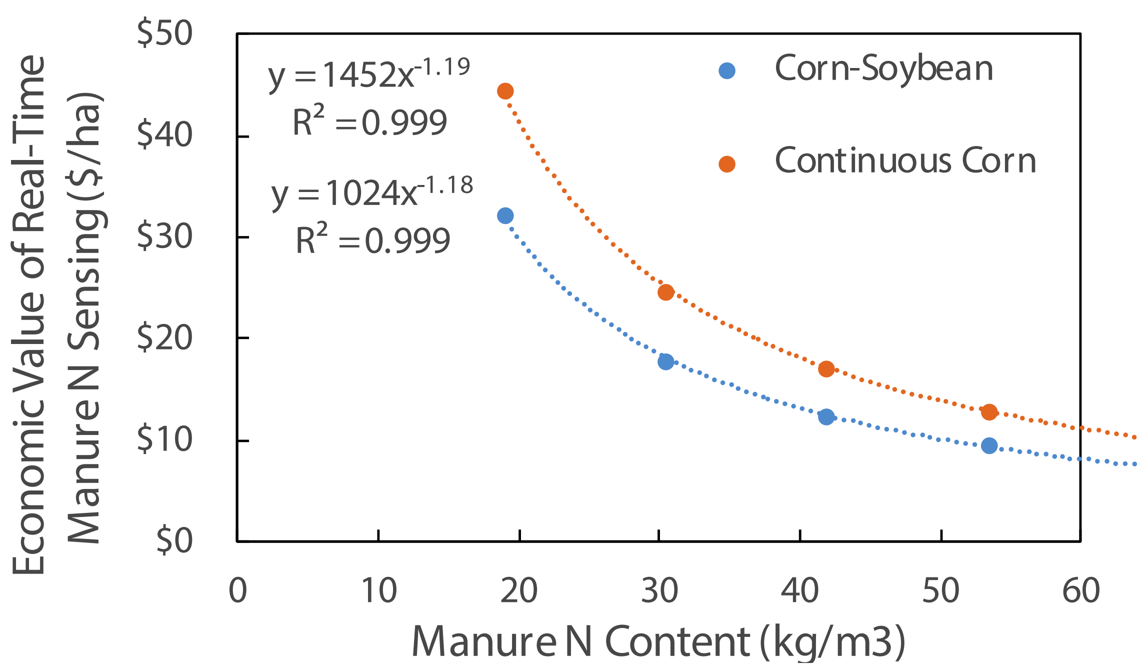

Figure 2. The estimated value real-time nitrogen sensing could provide by limiting yield losses from under application and saving extra nitrogen from over application based on ability to correct application rates on the go.

Estimated values from real-time nutrient-sensing were $7-30 per hectare in a corn-soybean rotation and $10-44 in a continuous corn rotation. Value came from correcting the application rate to avoid areas of over-application of nitrogen and alleviating yield reduction areas from areas receiving insufficient nitrogen. When the manure nitrogen content is low, approximately 20% of the value comes from over-application nitrogen savings; however, when manure nitrogen content is high, about 1/3 of the value comes from savings in areas where nitrogen over application would have occurred.

References

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