WHAT IS IT WORTH? THE ECONOMIC VALUE OF MANURE TESTING

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ABSTRACT. *Animal manure is a valuable fertilizer for crop production, but effective utilization requires knowledge of the manure's nutrient content. This warrants that the manure be sampled and tested to make informed management decisions. However, there has been low adoption of annual manure testing (ca. 20% of farms). Presumably, this is because farmers view the costs and efforts of testing to be greater than the benefits. To evaluate the monetary value of manure testing, a model was developed. Using published literature values of manure nutrient concentrations and other agronomic factors as inputs, this model assesses how production expenses and incomes change with knowledge of manure's nutrient content. The model suggests that when applying manure at a nitrogen-limited rate, sampling manure before application increases profits by \$20 to \$68 ha^{-1}, and sampling during application increases profits by \$3 to \$50 ha^{-1}. When applying manure at a phosphorus-limited rate, profits increase by \$4 to \$22 ha^{-1} when samples are analyzed either before or during application. These results illustrate that manure testing is economically beneficial and indicate that when application is nitrogen limited, manure should be sampled prior to application. If applying manure at a phosphorus-limited rate, sampling during application is recommended.*

Keywords. *Manure analysis, Manure management, Manure sampling, Value of a manure test, Value of information.*

Agriculture faces numerous challenges, among them volatile commodity prices and increased land and fertilizer prices. Furthermore, ameliorating the negative environmental impacts of agricultural production is increasingly important on a planet of finite size and increasing human population. Two environmental impacts of particular concern are the conversion of natural ecosystems for agricultural production, and the use and subsequent loss of macronutrients such as nitrogen (N) and phosphorus (P) (Tilman et al., 2001). As a result, there is greater scrutiny of nutrient use and loss from animal agriculture (Steinfeld et al., 2006). However, proper use of manure offers a redeeming virtue, as 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). Achieving these goals requires knowledge of manure nutrient contents so that appropriate application decisions are made. However, application decisions are often based on prior manure tests or reference values, such as those available from ASABE (ASABE, 2005) or Midwest Plan Service (Lorimor et al., 2004). Manure nutrient contents vary widely from farm to farm and from year to year (ASABE, 2005; Barth, 1985; Koehler et al., 2008; Payne, 1986; Rieck-Hinz et al., 1996), such that over- and under-application of nutrients is likely to occur frequently when relying on values from these references.

Many factors cause variations in the nutrient concentration of manure, including diet, housing type, manure storage type, environmental conditions, management techniques, and treatment practices (Barth, 1985; Payne, 1986; Rieck-Hinz et al., 1996; Bulley and Holbeck, 1982; Burton and Beauchamp, 1986; Clanton et al., 1991; Field et al., 1986; Frecks and Gilbertson, 1974; Lindley et al., 1988; Powers et al., 1975; Rieck, 1992; Safely et al., 1984; Westerman et al., 1985). Given the variability in composition, manure sampling and subsequent testing for nutrient composition is a critical component of proper management (Rieck-Hinz et al., 2003). Despite this, adoption of annual manure testing is relatively low. Dou et al. (2001) found that only 20% of farms surveyed (results from 994 farms) tested for manure nutrient content annually. Several factors could limit adoption of manure testing, including a perceived lack of profitability of manure testing, that it is time consuming, or that testing does not improve environmental quality. Gedikoglu and McCann (2012) found that the profitability of a practice is a critical factor for its adoption, and only 39% of their respondents agreed that manure testing was profitable, while 39% were neutral and 22% disagreed. Given this, it is clear that greater importance must be placed on documenting the economic value of manure testing.

Thus, the objective of this work was to determine, through economic modeling and the theory of the expected value of information, the profitability (or lack thereof) of

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annual manure testing. Our hypothesis was that manure testing improved farmer decision-making, ensuring appropriate application rates, and in so doing allowed the farmer to effectively capture the value of the manure. Our general approach was to calculate the expected value of information on the manure's nutrient content. The value of this information is the increase in expected profit that a farmer would derive from the collection and use of the new information relative to the expected outcome achieved without the information, i.e., using the assumed nutrient concentrations. Three "knowledge level" options are compared: (1) no manure nutrient testing, (2) pre-application manure testing, and (3) sampling during manure application with nutrient results available post-application. We performed additional analyses to evaluate how uncertainty in manure test results influence the perceived value of the manure test.

METHODS

In determining the value of the manure test, it is important to understand how a farmer can use the information gained from the test results, i.e., how having this information alters the farmer's nutrient management and affects the farm profit. This is a complex topic, as almost limitless possibilities exist. In this evaluation, we assumed that the manure application method would be either injection or immediate incorporation to maximize N utilization. Additionally, we assumed that best management practices for manure application timing were followed; as a result, the yield response to available N (defined here as the sum of ammonia N and organic N expected to mineralize in the first growing season) would be the same as the yield response to mineral N fertilizer. Finally, we limited crop rotation choices to continuous corn and corn-soybean rotations, as these represent the dominant rotations in the upper Midwestern U.S. However, our model, which is available upon request, is readily adjustable to allow for analysis under different sets of assumptions. The impacts on the value of the manure test of N-limited or P-limited application, as well as when sampling or testing was conducted, were handled by evaluating all cases. Finally, the basis of this effort was that farms intend to use their manure resources to support crop production. In cases where farmers have insufficient land to use all their manure resources, they can only extract the value of the manure test if they can find buyers for the manure nutrients.

In addition to nitrogen, manure also contains phosphorus, potassium, and organic matter, which can also provide value to the farmer. For the purpose of this study, we assumed that these factors are of minimal importance in determining the value of the manure test, with only the information on the manure's N content providing value. This does not imply that these other nutrients do not contribute to the value of the manure, only that more accurate information on their concentrations does not change the immediate nutrient management decisions related to either supplemental fertilization application or wasted nutrient value. For example, a typical P management strategy is to maintain soil P at sufficiently high levels that negligible crop

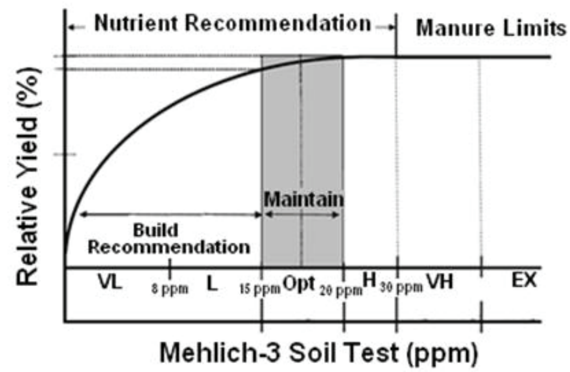

Figure 1. Conceptual schematic of crop response to soil test phosphorus level (based on Dodd and Malarino, 2005).

response would result from P application (fig. 1) (Dodd and Malarino, 2005). This "banking" strategy makes crop yields fairly insensitive to P application in a particular year, and thus improved information on manure P concentrations does not provide the opportunity to apply supplemental P to improve profit. In the case of slight over-application, an argument could be made that this P could have been applied elsewhere, and thus this represents a lost opportunity cost. However, as P is strongly retained in the soil, most of this value can be recovered in subsequent years, as long as appropriate future manure and fertilizer application decisions are made (although impacts on water quality may result). Consequently, greater knowledge of the exact P content of the manure does little to influence a producer's management of the crop. Similarly, testing results for potassium and organic matter would generally not affect fertility management decisions.

Our methodology was to estimate the profit that would have been made if the manure was assumed to have a "typical" nutrient composition and then to compare this to the profit generated if the actual nutrient composition was known. To make this evaluation, an economic model was developed as an Excel spreadsheet. The model compared the costs and revenue of corn production. Performing this comparison required cost estimates of field activities, the cost of purchased inputs (herbicide and seed) (table 1, based on Edwards et al., 2014), the sale price of corn, the cost of synthetic N fertilizer, the maximum potential yield, and the response of the corn to the applied N.

The maximum corn yields in corn-soybean and continuous corn rotations were set at 12.55 Mg ha^{-1} (200 bushel per acre) and 10.37 Mg ha^{-1} (175 bushel per acre), respectively (Pederson et al., 2012). The cost of synthetic N was set at \$0.85 kg^{-1} N (USDA, 2014), and the sale price of corn was set at \$4.91 bu^{-1} (Quotecorn, 2014). Corn yield

Table 1. Costs of field activities associated with corn production.

Field activity	Cost (\$ ha^{-1})
Tillage	\$71.17
Corn planting	\$44.11
Spraying	\$18.66
Herbicide	\$49.42
Harvesting and drying corn	\$148.90
Seed corn	\$294.00
N application (synthetic fertilizer)	\$31.38

was calculated as the product of maximum yield and the estimated percent yield that was achieved, with the relationship between N application rate and corn yield approximated using the Mitscherlich model (NRC, 1961) (eq. 1):

$$y = 100(1 - \exp[-c(x + b)]) \quad (1)$$

where y is the percent of maximum yield, x is the N application rate (kg N ha^{-1}), b is a constant that estimates the amount of soil-derived available N, and c is the Mitscherlich effect factor. This equation was fit to yield response curves taken from the Iowa State University Corn Nitrogen Rate Calculator (ISU, 2004). Fitted equations 2 and 3 represent response curves for corn after soybean and continuous corn rotations, respectively, and assume that yield will be limited by nitrogen:

$$y = 100(1 - \exp[-0.016611(x + 63.59444)]) \quad (2)$$

$$y = 100(1 - \exp[-0.012037(x + 38.57373)]) \quad (3)$$

These curves account for leaching and denitrification losses of N; however, since they are based on synthetic N, ammonia volatilization losses and first-year available N are accounted for in the model. First-year available N values were 100%, 60%, 40%, and 40% for swine, layer, dairy, and beef manures, respectively, and ammonia volatilization values were estimated as 1% for swine and dairy manure slurries applied by injection and 3% for solid layer and beef manure applied by broadcast with immediate incorporation (Sawyer and Mallarino, 2008). These assumptions are summarized in table 2. The corn response to N functions used here are only accurate for Iowa (fig. 2); applying this model to other areas requires the crop response to N for that location and crop rotation.

The cost of manure application varies based on the application rate, application method, and the distance the manure is transported (Mulhbauer et al., 2008). The cost of manure application with injection and broadcast as a function of manure application rate is shown by equations 4 and 5, respectively:

$$y = 0.1456x^{-0.32} \quad (4)$$

$$y = 0.0256x^{-0.157} \quad (5)$$

where y is the manure application cost (\$ L^{-1}), and x is the manure application rate (L ha^{-1}). It was assumed that all manure would be applied within 1.6 km (1 mile) of the facility and that a transportation distance surcharge would not be needed. Handling situations where the manure is transported farther than this can be facilitated by adjusting the cost functions used in the model.

The desired nutrient application rate was set either to the maximum return to nitrogen (MRTN) calculated using the N-rate calculator (ISU, 2004) if the manure application was N-limited (i.e., limited by the amount of nitrogen applied) or to the estimated P removal rate (single year of corn in continuous corn or the sum of corn and soybean removal in a corn soybean rotation) if the manure application was P limited. The choice of N-limited or P-limited manure application is typically the result of government regulations. For example, in Iowa, determining if a manure application will be limited by the amount of N or P applied requires following steps in a manure management plan. This document requires periodic collection of soil samples and determining a phosphorus index.

The MRTN value was determined using the Iowa State University Corn Nitrogen Rate Calculator (ISU, 2004). The manure application rate was calculated based on the desired N (or P) input and the expected N (or P) content of the manure, i.e., the concentration that would have been assumed if no sample was collected. The nutrient content was approximated to be 0.70% ±0.16% N with 0.21% P for deep-pit swine manure, 1.85% ±0.55% N with 0.60% P for layer manure, 0.30% ±0.12% N with 0.13% P for dairy slurry, and 1.18% ±0.39% N with 0.50% P for beef manure from an earthen lot (ASABE, 2005; Koehler et al., 2008; Lindley et al., 1988; Peters and Combs, 2003; Sommer et al., 1993). A summary of these concentrations is provided in table 2. A normal probability distribution function was used to assess the percent chance of different nutrient application rates occurring. The expected profit was calculated as the sum of the profit associated with each N application rate times the probability of that N application rate occurring. If application was P limited, the same procedure was followed, but the manure application rate was set based on the P application.

This approach offers a method of handling the uncertainty of the manure's nutrient composition, as it evaluates the possibility of the N application rate differing from our desired rate as a result of lack of knowledge of the manure's actual nutrient content. In so doing, it facilitates evaluation of different application strategies, such as applying insurance N, to account for the uncertainty of the manure's nutrient content. This is illustrated in figure 3 for the case of deep-pit swine manure applied to corn in a corn-

Table 2. Summary of manure N and P concentrations, first-year N availability, and ammonia volatilization used in assessing the value of the manure test (SD = standard deviation).

Manure Type	Manure N Content, Mean (SD) (%)	Manure P Content (%)	First-Year N Availability (% of N applied)	Ammonia Volatilization (% of N applied)
Swine	0.7 (0.16)	0.21	100	1
Dairy	0.3 (0.12)	0.13	60	1
Layer	1.85 (0.55)	0.6	40	3
Beef	1.18 (0.39)	0.5	40	3

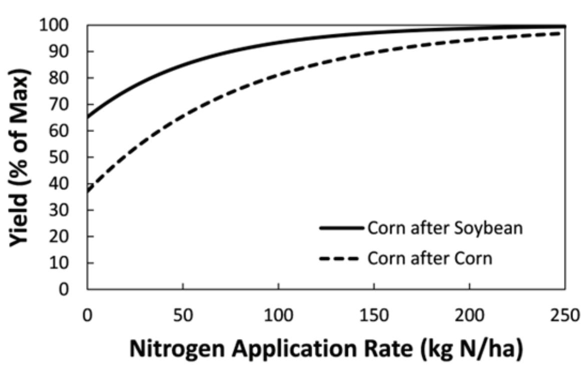

Figure 2. Yield response curves of corn to nitrogen application for corn after corn and corn after soybean rotations (based on Sawyer et al., 2006).

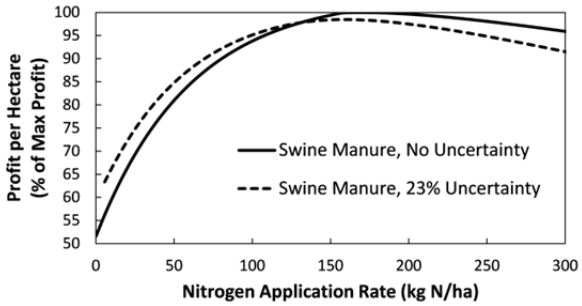

Figure 3. Effect of nitrogen application rate and uncertainty in manure nutrient content on profitability (uncertainty represents the coefficient of variation)

soybean rotation. Applying N precisely at our desired application rate, i.e., no uncertainty in the manure's N content, results in a rapid increase in profit that maxes out and then slowly declines. With uncertainty in the N content, the response is more subdued and reaches a maximum profit lower than that obtained for the no-uncertainty case, indicating that the lack of information has reduced the maximum expected profit. It also illustrates that the ideal N application rate did not change much (it was slightly lower) with the uncertainty in the nutrient content of the manure.

In practice, two methods exist for sampling and testing manure. The first method is to sample the manure before application so that the test results can be used to select the application rates. The second method is to sample the manure during application and use the test results afterward to verify the amount of N applied. When a farmer chooses to sample the manure affects how the nutrient concentration information can be used. One potential issue with sampling manure prior to application is that changes can occur in the manure composition before the manure is land applied (Sommer et al., 1993), or it may not be possible to thoroughly mix the manure to ensure a representative sample (Rieck-Hinz et al., 2003). This results in uncertainty about the true nutrient content of the manure at the time of application.

If a sample is collected during manure application, it has the advantage of representing what is actually applied. It has also been subjected to the loss mechanisms that additional storage time, agitation, transport, and land application may have caused, making the sample more representative. A limitation of this method is that the results are not available to calculate the ideal manure application rate at the time of application and can only be used to validate the amount of nutrient applied. If the actual N content of the manure was less than the estimated N content, then N was applied at a rate less than the MRTN. In this case, the farmer can choose to add supplemental synthetic N to meet the N needs of the crop. The cost of applying supplemental N was calculated as the difference between the MRTN and the manure N application rate, multiplied by the cost of synthetic N plus the cost of applying synthetic N. The value of the manure test was calculated as the net profit that could be obtained by testing manure and applying supplemental N when appropriate, minus the profit that was obtained if manure application was assumed to be sufficient. If excess N was applied, then the value of the manure test was assumed to be zero, as the producer could not make a management change to reclaim the value of the N applied.

The process of valuing a manure test is illustrated in figure 4, including (a) the probability of different N contents in deep-pit swine manure, (b) the estimated profit if the manure application was based on an assumed standard concentration, (c) the profit if the manure was tested prior to application and applied to provide the maximum return to

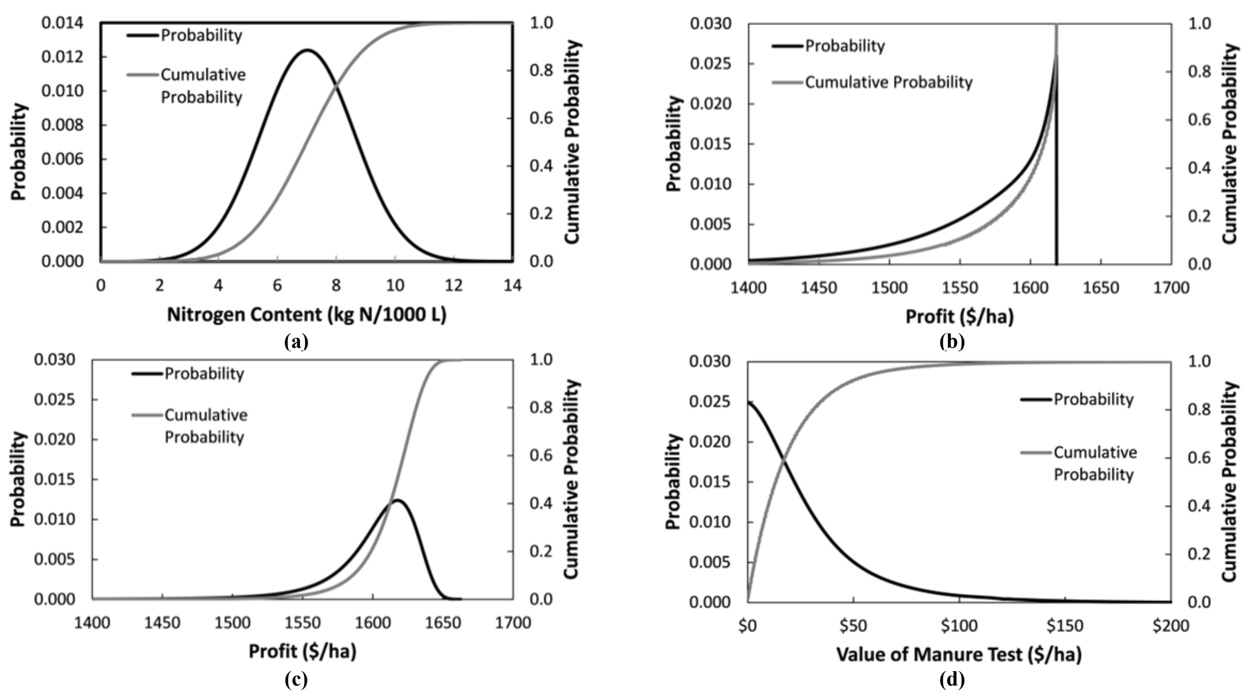

Figure 4. (a) Probability of different nitrogen contents of deep-pit swine manure, (b) probability of different profits due to different nitrogen contents of manure assuming standard rates, (c) expected profit from applying manure of a known composition at the maximum return to nitrogen, and (d) expected value of the manure test (based on curve b – curve c).

N, and (d) the value of the manure test. The value of the manure test was calculated by subtracting the profit estimated for each N content of manure of unknown composition from the profit estimated for the same N content assuming the manure had been tested. For manures with low N content, excessive manure application rates could result; thus, we choose to limit the manure application rate to 254,000 L ha^{-1} (equivalent to 1 acre-inch of moisture addition). If manure application was hydraulically limited, supplemental N was provided to achieve the MRTN application rate if supplemental N application increased profits.

RESULTS AND DISCUSSION

The probability of the manure test being profitable varies based on the type of manure. This is related to the uncertainty of the manure's N content. Manure types with higher coefficients of variation exhibit more spread in their probability distribution function and as a result have an increased chance of being drastically different from the standard value for N concentration. This increases the value of the manure test, as there is a greater probability of the new information creating value by improving management options.

Similarly, manure testing offers more potential value in a continuous corn rotation than in a corn-soybean rotation when manure application is N limited (table 3), i.e., if the manure application rate is limited by the amount of nitrogen the farmer can apply. This is because corn yield exhibited greater sensitivity to N application in the continuous corn rotation than in the corn-soybean rotation. In general, the results showed that pre-application sampling was a better strategy when manure application was limited based on N. However, if manure application was P limited, sampling during application would be preferable. This occurred because the value of the manure test is based on N, and thus creating a strategy to ensure sufficient N to support crop growth without wasting N is essential to maximize value. One interesting finding is that the manure test was more valuable in corn-soybean rotations than in continuous corn rotations when manure application was P limited. This result was driven by the assumption of applying a single-year phosphorus requirement in the continuous corn rotation and the two-year rate in the corn-soybean rotation.

Table 3. Estimated value of the manure test for different manure type and crop rotations.

Manure Type and Crop Rotation	Pre-application N limited ($ ha^{-1})	Pre-application P limited ($ ha^{-1})	During Application N limited ($ ha^{-1})	During Application P limited ($ ha^{-1})
Swine slurry				
Corn-soybean	$19.94	$22.09	$3.38	$22.07
Corn-corn	$30.66	$10.62	$8.37	$10.61
Layer manure				
Corn-soybean	$32.66	$14.37	$9.92	$14.37
Corn-corn	$50.04	$6.78	$20.45	$6.78
Dairy slurry				
Corn-soybean	$29.72	$9.82	$27.44	$9.82
Corn-corn	$67.83	$4.93	$50.46	$4.93
Beef feedlot scrapings (earthen lot)				
Corn-soybean	$31.54	$7.13	$13.94	$7.13
Corn-corn	$50.20	$3.72	$27.48	$3.72

As some of the model inputs are quite variable, e.g., the prices of corn and fertilizer, understanding the sensitivity of the model is important for evaluating how different factors impact the value of the manure test, as well as the circumstances that maximize the value a farmer receives from manure testing. Based on the above results, we focused our sensitivity analysis on pre-application sampling for N-limited manure application and sampling during application for P-limited manure application. Swine manure (with the highest available N:P ratio) was used to assess the sensitivity in the case of pre-application sampling, while beef manure (with the lowest available N:P ratio) was used to assess the sensitivity in the case of sampling during application. The sensitivity analyses were conducted by varying one model input at a time to assess the impact on the value of the manure test. Each parameter was varied by 25% from its assumed value, and the value of the manure test was then plotted as a function of the varied input parameter. The sensitivity was calculated as the change in value of the manure test per unit change in the input parameter that was varied.

The results indicated that the value of the manure test was positively related to the price of corn, maximum corn yield, cost of synthetic N, and the coefficient of variation of manure N content (table 4). The manure test value was positively related to the cost of synthetic N because limiting N waste provided value to the farmer. Similarly, the manure test value increased as corn price increased because the value of applying sufficient N to achieve optimum yields increased, allowing supplemental N in more cases. The same logic applies to why the manure test value increased as the coefficient of variation, or uncertainty of the manure N content, increased. Wider variation in the expected N content results in a greater probability of either over- or under-application, with the manure test allowing better use of the nutrient value. The manure test value also increased as the maximum corn yield increased because small changes in N application led to greater yield response.

DEMONSTRATION

These theoretical concepts were applied to a swine farm

Table 4. Sensitivity of expected manure test value to corn price, maximum corn yield, cost of synthetic N, and coefficient of variation of manure nitrogen content for N-limited application of swine manure sampled before application and for P-limited application of beef manure sampled during application for corn-soybean (CS) and corn-corn (CC) rotations.

Input Parameter	Calculation	Swine Manure Sampled before N-Limited Application CS	Swine Manure Sampled before N-Limited Application CC	Beef Manure Sampled at P-Limited Application CS	Beef Manure Sampled at P-Limited Application CC
Corn price	$ ha^{-1} fertilized / $ Mg^{-1} corn	0.07	0.10	0.01	0.01
Maximum corn yield	$ ha^{-1} fertilized / Mg corn ha^{-1}	0.92	1.68	0.92	0.64
Cost of synthetic N	$ ha^{-1} fertilized / $ kg^{-1} N	13.41	19.15	4.89	2.49
Coefficient of variation	$ ha^{-1} fertilized / 1% change in COV	1.00	1.92	0.22	0.11

with 1000-head capacity and deep-pit manure storage that used a continuous corn rotation. On average, the facility generated 4 L of manure per head per day. This farm has collected and tested manure samples every year for the last five years. The first four years of manure sample values were 0.84%, 0.72%, 0.98%, and 0.62% N, with an average and standard deviation of 0.79% ±0.16% N. The N content for the current year was 0.92% N.

If no sample was tested, this operation assumed that the manure had an available N content of 0.79%, the average of the previously collected samples. Using pre-application sampling and assuming that manure application was N limited, the value of the manure test would be \$30.96 ha^{-1}. Assuming that the manure sample is representative of all the manure from this building, the overall value of the sample was \$1,759 (the farm would have applied manure to 56.8 ha). This represents a good return on investment, as the approximate cost of obtaining this information would be \$50 for manure testing, \$50 for shipping the manure to the testing lab, and \$100 for the farmer's time to collect, label, and ship the sample, giving a return of almost 9:1. If manure application was P limited and manure was sampled during application, the estimated value would be \$14.20 ha^{-1}. In this case, the manure was applied to 112 ha, so the actual value of the test would be \$1,589.

IMPERFECT INFORMATION

Thus far, we have assumed that manure tests provide perfect information. In reality, this is not the case, as some uncertainty remains regarding the true nutrient composition of the manure. This imperfect information may impact the value of the manure test, and this can be assessed by evaluating the difference in the expected value of the test before sampling and then evaluating the value of the test again with some uncertainty remaining. To evaluate the impact, an analysis was performed for deep-pit swine manure applied to a corn-soybean rotation at both N-limited (sampled before application) and P-limited (sampled during application) rates. In both cases (fig. 5), greater benefit was gained from the initial reduction in N uncertainty than from perfect knowledge, as indicated by the steeper slope near 0% reduction compared to the 100% reduction portion of curve. Overall, these results indicate that the lack of perfect information on manure sample decreases the expected value of the manure test. However, even with 5% to 10% COV remaining in the manure's nutrient concentration (a 56% to 78% reduction in uncertainty), the farmer would recover 70% to 98% of the manure test's expected value. These reductions in uncertainty are typical of what would be expected from representative samples that were sent for nutrient analysis.

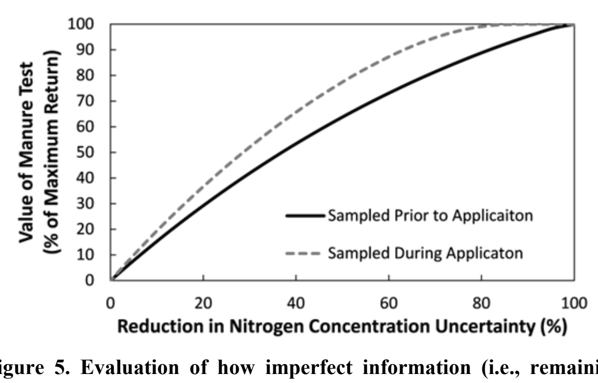

Figure 5. Evaluation of how imperfect information (i.e., remaining uncertainty in manure nitrogen content) impacts the value of the manure test for manure sampled before application at an N-limited rate and for manure sampled during application at a P-limited rate. Example calculations are for for deep-pit swine manure applied to the corn phase of a corn-soybean rotation.

In this work, we assumed that either injection or immediate incorporation would be used for manure application. This assumption was based on best management practices for improving nitrogen use efficiency, and injection or immediate incorporation are common application strategies in Iowa for this reason and for odor control. However, some farmers still choose to surface-apply manure. This can occur for numerous reasons, including the use of truly no-tillage systems or using irrigation methods, such as pivots or sprinklers, for manure application. Although putting a true value on manure testing with these systems would require revising the model to incorporate the correct assumptions, we can get some idea of what to expect using the concept of imperfect information. In the case of liquid manure broadcast with no incorporation, Sawyer and Mallarino (2008) suggested that 10% to 25% of the N will be lost to volatilization, for an average of about 17.5%. Although they do not provide a statistical distribution for this value, we assume they are using a 95% confidence interval. Therefore, our uncertainty in the amount of nitrogen lost from just potential volatilization would be at least 5%. Assuming that we were working with deep-pit swine manure, this would mean that we have reduced our nitrogen application uncertainty by 80% and would still recover approximately 90% of the manure test value. However, other uncertainty, such as variability in the manure's composition as it comes out of storage, variation in manure application rate, and variation in first-year nitrogen availability, might further increase the uncertainty and reduce the value of the manure test.

CONCLUSIONS

In many ways, farming is often an exercise in decision-making in uncertain conditions. Agricultural systems are complex, highly variable, and conditions are continuously changing. Moreover, the variable conditions mean that the farmer often lacks information that could be used to make more informed decisions. Sampling and testing can provide farmers with more information, which they can use to improve their decisions. This work demonstrated that manure testing is an important part of maximizing the value of manure; moreover, it is known to be a best management practice for environmental protection.

Based on our results, if manure is being applied at an N-limited rate, we recommend collecting the sample to be used in determining the manure application rate before the application. If manure is being applied at a P-limited rate, the manure sample should be collected during application, used to verify the amount of N applied, and then used to select an appropriate rate of supplemental N fertilization.

Following these recommendations provides the farmer with the greatest economic opportunity. Our work suggests that when applying manure at an N-limited rate, sampling manure before application increases profits by \$20 to \$68 ha^{-1}. When applying at a P-limited rate, additional profits of \$4 to \$22 ha^{-1} were estimated. We also found that manure sampling is inherently more valuable in manure management systems that have greater variability in manure nutrient content, such as outdoor storage where weather can have a large impact. Finally, additional variables, such as the ability to consistently control the application rate, estimate the amount of ammonia volatilization, and estimate first-year nitrogen availability, all impact the value of the manure test, as they mean that the manure sample estimate is imperfect, and additional variability remains.

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