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Optimizing the value of manure nutrients through testing and treatment

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Optimizing the value of manure nutrients through testing and treatment

by

Kelsey B. Regan

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agricultural and Biosystems Engineering
& Sustainable Agriculture

Program of Study Committee:
Daniel S. Andersen, Major Professor
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Ames, Iowa

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ABSTRACT

As agricultural production increases and demands for more sustainable production rise, it becomes necessary to develop and improve best management practices that allow farmers to efficiently utilize their inputs while minimizing unwanted losses. In addition to this, farmers must utilize recommendations in a way that is economically beneficial to their operation. Large-scale animal production needs improved best management practices because of the complexities involved. Animal manure is a valuable fertilizer for crop production, but effective utilization requires knowledge of the manure's nutrient content and retaining as much of the nutrients as possible in the manure. This thesis explores two different possible best management practices recommended for manure management: testing manure for nutrient content and treating manure with an additive called More than Manure. Based on the research, it showed that testing manure for nutrient content is an economically and environmentally beneficial recommendation, while using More than Manure did have a positive effect at ammonia retention, it was not sufficient economic benefit to justify use.

CHAPTER I

INTRODUCTION

Manure is an important resource for crop nutrients; however, modern animal confinements can cause odor concerns and certain manure management practices might result in nutrient loss. Various methods have been proposed to retain nutrients and reduce odor, thus increasing the value of manure. However, methods vary in effectiveness and applicability to farmers. This work discusses several methods to improve effectiveness in managing manure and encouraging greater implementation of best management practices.

MAJOR KNOWNNS

- Testing manure allows a farmer to match manure application to their nutrient need
- Acidification of manures can reduce ammonia emissions.
- Treating manure to reduce odor is valuable especially when animal confinements are close to urban areas

VALUE OF TESTING MANURE FOR NUTRIENT CONTENT

Testing manure for nutrient content has been recommended for a number of years to ensure that manure nutrients are applied at the correct rate. However, a study by Dou et al. (2001) showed that only 20% of surveyed farms actually test their manure on an annual basis. Many factors can cause variations in manure nutrient concentrations from year to year including climate, diet and manure management practices (Lindley et al., 1988). For this

reason, it has been suggested that farmers could obtain an economic value from testing manure because if manure is over applied, then the nutrients are wasted because they could have applied them to other areas of land. If they are under applied, then they lose money because of reduced yields. Also, there are environmental benefits to testing manure because when farmers know the nutrient content of their manure, they can chose an appropriate application rate so nutrients are not over applied where they are more likely to be lost to the environment.

EFFECT OF MANURE TREATMENTS FOR NUTRIENT RETENTION AND ODOR MITIGATION

Confined animal feeding operations (CAFOs) can be the source of offensive odors. Citing of CAFOs and climate factors can transport these odors to areas where they can impact people who are not involved in livestock production. One major effect of odors is the possibility for a negative effect on human health. Schiffman and Williams (2005) cited asthma like symptoms, headaches, sinusitis, nasal and throat irritation, muscle aches and pains for people living near CAFOs as well as acute and chronic respiratory impairment of workers in swine facilities. This resulted in regulations in North Carolina that new swine facilities must have Environmentally Superior Technologies to address odor and environmental problems (Schiffman and Williams, 2005). Odor can also have a negative effect on housing prices near CAFOs. Palmquist et al. (1997) found that proximity caused a statistically significant reduction in house prices of up to 9% depending on the number of hogs and their distance from the house. The effect on the price of a house from opening a new operation depended on the number of hogs already in the area. For this reason, implementing technologies that reduce odors can be economically valuable.

Chemical additives have been suggested to reduce odor and retain nutrients in manure, especially products that cause acidification because this has the potential to reduce ammonia volatilization. The developers of a product that uses an acidic copolymer, called More than Manure, claim that it is “The first and only manure manager proven to reduce: Nitrogen loss from leaching, volatilization and denitrification, Phosphorus lock-up”, however research with similar products has had mixed results, especially with phosphorus stabilization. No studies have been performed using More than Manure, but some studies have been done with AVAIL, which has the active ingredient of partial sodium salt of maleic-itaconic copolymer in 30% w/w, while More than Manure uses partial ammonium and calcium salt of maleic-itaconic copolymer in 40% w/w. Hopkins (2013) found that when potatoes were treated with monoammonium phosphate and AVAIL, they had higher yields than without AVAIL. Guertal and Howe (2012) used AVAIL as P stabilizer with perennial rye grass and synthetic P and results indicated that AVAIL had the potential to improve available phosphorus. Chen et al. (2014) found that the effectiveness of AVAIL greatly depends on the amounts and forms of amorphous Fe/Al oxide minerals, which are normally extracted by 0.2 M NH_4 -oxalate (pH 3, with no significant effect on mobilizing P in soils pH > 7). Chen et al. (2014) concluded that the amount of the maleic-itaconic acid copolymer added to fertilizer P based on the recommendation is too small to have any significant effect on reducing P-retention capacity of any soils. When used as a urease inhibitor, Chen et al. (2014) found that laboratory incubation studies showed that the copolymer is not a urease inhibitor at all and the rate of urea hydrolysis was not reduced by the copolymer as compared with that of urea alone. When used to prevent ammonia volatilization, Chen et al. (2014)

found that results from urea treated with and without the copolymer did not differ. This indicated that the copolymer did not reduce NH_3 volatilization from urea in Renshaw soil and the copolymer actually enhanced NH_3 volatilization of urea compared with urea alone, probably due to the stimulation of urease activity by the copolymer. Therefore, further testing should be done on acidic copolymers to determine if their use should be recommended as a best management practice, especially for manure treatment.

KNOWLEDGE GAPS

- Annual manure testing could be profitable to farmers.
- Acidifying manure makes ammonia less volatile. Acidic copolymers have been tested with synthetic nutrients but not manure and it is unknown what components of manure could affect the function of the acidic copolymers.

RESEARCH OBJECTIVES

The overall goal of this project was to determine how manure nutrients can be used more efficiently. Knowing the nitrogen content of manure can help farmers determine an appropriate application rate and treating manure can help retain ammonia. The value of a manure nitrogen test can be determined through an economic model and the effectiveness of manure treatment can be determined through pilot scale testing. The objectives of both the economic model and the pilot-scale treatment study are explained below.

VALUE OF MANURE MODEL

1. Develop an economic model to determine if annual manure testing is a good economic investment for farmers.

2. Analyze return on investment for different crop rotations, manure types and application rates.

EFFECT OF ACIDIC COPOLYMERS

1. Determine if acidic copolymers are effective at reducing manure odors and stabilizing nutrients
2. Test different amount of acidic copolymers to see which rate is most effective.
3. Test acidic copolymer effectiveness in a continuously ventilated system to model the effectiveness in a barn setting.
4. Determine if there is a difference in the effectiveness of acidic copolymers on crusted and uncrusted manures

THESIS ORGANIZATION

Chapters 2 and 4 are literature reviews which summarize existing research in the areas studied. The first literature review is about the value of information and how it can be used to bridge the gap between scientists and farmers by linking the environmental and economical aspects of farming. The second literature review covers effects of manure treatments on nutrient retention and odor mitigation.

Chapters 3 and 5 address the research objectives outlined above. Chapter 3 is titled “What Is It Worth? The Economic Value of Manure Testing”, which is modified from a paper published in *The Transactions of the ASABE*. This paper describes an economic model developed to determine the value of testing manure for nitrogen content.

Chapter 5 is titled “Efficacy of ‘More than Manure’ to Reduce Ammonia, Greenhouse Gases and Odors from Stored Swine Manure.” This study used a pilot scale experiment to determine how a sorptive additive affected emissions from swine manure.

Chapter 6 gives conclusions that were gained from the previous five chapters. Throughout the thesis, references are included at the end of each chapter.

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CHAPTER II

BRIDGING THE GAP BETWEEN SCIENTISTS AND FARMERS WITH THE VALUE
OF INFORMATION

Kelsey B. Regan

UNDERSTANDING THE COMPONENTS OF SUSTAINABLE AGRICULTURE

Concerns over the sustainability of agriculture have led to many new recommendations from scientists to help reduce potential negative impacts of modern agriculture. Unfortunately, there can be limitations to farmers adopting these practices because there is often a disconnect between recommendations from scientists and the ability or willingness of farmers to follow those recommendations. Although recommendations may be helpful in improving the sustainability of a farm, they can come with extra time or money requirements to farmers. Improving the usefulness of the information to the farmers can be achieved by considering three main components to sustainability: social, economic, and environmental, however the relationships between the three are often poorly understood (Munasinghe, 1993).

Often times, the environmental and economic aspects between scientists and farmers are at odds with each other, because environmental best management practices can come with an added cost. For example, cover crops have been recommended to reduce erosion, but the seeds are an additional cost and the activities associated with managing the cover crops take extra time and there are not immediate economic returns. For this reason, using the concept of value of information could help scientists to demonstrate the potential economic benefits of their recommendations to farmers. Although there are many important core ideas of sustainable agriculture, the two that I will focus on are the importance of the concept of

value of information in sustainable agriculture in achieving a balance between environmental and economical sustainability.

THE IMPORTANCE OF BEST MANAGEMENT PRACTICES IN IMPROVING SUSTAINABILITY

To continue to increase agricultural production, more emphasis will need to be placed on sustainability. Developing more information about how agricultural production can affect soil, air, and water resources and the impact farming activities can have on them on them is an imperative first step to changing practice; however, complete evaluation, including economics, is necessary to place the farmer's choice in context.

There are numerous parameters in agriculture that can be measured – soil nutrient concentrations, crop yields, weather conditions, etc. The measurements that farmer's choose to take and how they interpret and use the information from it can have significant impacts on the environmental and economic well-being of their farm. For example, about 60% of farmers use precision agriculture to create yield maps of their fields after harvesting corn through sensors that monitor the amount of corn harvested in a specific area (Thorp et al., 2008). These maps can indicate areas where production is lower, which may influence farmers to implement additional management practices to increase yields in those areas. However, there are many factors that could cause lower yields in different areas, such as higher nutrient needs, poor drainage, and pests, so it can difficult for a farmer to know which management strategy would be most effective at improving yields. Helping farmers understand how to better utilize this information can improve their profits while reducing potential negative environmental impacts.

One of the most prevalent issues to Iowa agriculture is nutrient management. Iowa farmers do important work producing food, feed, fuel and fiber; however, there are externalities such as nutrients lost during production that can cause direct and indirect harm to people and ecosystems that are not involved in agriculture. For this reason, it is necessary to explore a variety of ways that could improve this agricultural paradigm. Developing recommendations to retain nutrients can reduce unwanted losses, which will reduce the environmental impact of agriculture as well as the productivity of the farm, thus increasing sustainability.

IMPORTANCE OF ECONOMICS AS IT RELATES TO THE ENVIRONMENTAL ASPECTS OF FARMING

Economics are a very important component of sustainable agriculture but often the economics of different best management practices are poorly understood. In most cases, farmers are aware that their actions can have a negative effect on the environment and they are interested in taking action to reduce that impact, but time and financial constraints can limit their ability to implement or continue best management practices. Carr and Tait (1991) noted that although farmers surveyed had favorable attitudes towards conservation, there was not a strong relation in their attitudes and actually adopting conservation practices, while farm productivity and ascetics played a more important role in their decisions. This could be because of the potential negative economic impact to their business by adopting those practices.

Farming is a very complex business, so it is important for farmers to make decisions that will have a positive financial benefit so they and future generations of their family will be able to continue farming (Willock et al., 1999). Similar to other businesses, there is a need for continued economic growth to achieve economies of scale and to reduce unwanted costs,

which has a negative impact on environmental sustainability. For this reason, there needs to be a balance between conservation and economic benefit. Table 1 shows different agricultural management practices and their potential environmental and economic impacts.

Table 1: Environmental and economic impacts of different management practices.

Practice	Environmental Impact	Economic Impact
Crop Rotation	+	+
Contour Strip Cropping	+	+
Controlled Drainage	+	+
Conservation Tillage	+	+
Rotational Grazing	+	+
Terrace	+	N/A
Contour Farming	+	N/A
Cover Crops	+	N/A
Grassed Waterways	+	N/A
Feedlot/Wastewater Filter Strip	+	-
Constructed (Treatment) Wetlands	+	-
Buffer Strips	+	-
Manure Broadcasting without Incorporation	-	-
Deep Tillage	-	-

+: positive impact

-: negative impact

N/A: possible long-term benefit, but no data available

A major limitation to farmers implementing new conservation practices are the low profit margins involved with farming. Farmers want to be able to get a return on their investment, so placing a value on the implementation of a best management practice can help them decide whether it would be financially beneficial to them. Some practices require little change to a farmer's system and can result in economic benefits that are realized within a production year as a result of higher yields, such as utilizing a crop rotation. Other conservation practices come with an economic benefit when they are part of a government subsidy or regulation, such as implementing cover crops or terraces to reduce erosion, but many times voluntary conservation practices are seen as just an added cost to their already

costly operation. Some best management practices come with direct economic benefits in the short-term; however, others, especially those related to soil conservation can have economic benefits that are achieved in the long-term. For example, the yield benefits resulting from reduced erosion from conservation tillage may not be evident for many years. For this reason, it can be difficult for farmers to invest money in implementing a practice if they might not realize the benefits until many years later (Munasinghe, 1993). It can be difficult for farmers to know if the long-term returns can be economical when they receive the information.

IMPROVING SUSTAINABLE AGRICULTURE THROUGH INTERDISCIPLINARY WORK

There has always been a challenge of getting information about sustainable agriculture to farmers and the challenge that farmers have in deciding which information they should use. Many times the work that academic researchers do is very discipline specific and offer limited opportunities for interdisciplinary thinking or approaches. This problem is described in the following quote about university education: “Rather than training students to examine a problem and apply whatever tools are necessary to address it, universities typically train students in a set of discipline-specific tools that they are then expected to apply to all problems” (Farley et al., 2005). This approach to science can be a problem because agriculture is very interconnected, so without seeing the big picture there can be potential negative unintended consequences. Considering interdisciplinary aspects can help scientists develop a better understanding of the big picture of agriculture, and help in evaluating in how different components of agriculture are related.

Farmers can mistrust information from scientists because scientists sometimes fail to understand the whole systems approach of farming. Scientists often do not understand the complexities of farm management, so researchers tend to make suggestions based on their

own views of how the farm is managed rather than understanding the processes already in place and incorporating their suggestions into them (McCown, 2002). A potential solution could be to develop better models of agricultural economics that incorporate nonmonetary aspects. Typical agricultural decision-making tools are based on a cost-benefit analysis. This has limitations for environmental aspects because it usually only incorporates direct costs, but sustainability can have many non-monetary aspects. For this reason, Tiwari et al. (1999) recommends using multi-criteria-decision-making techniques, which can take into account objectives, such as social or environmental components that cannot be quantified with a monetary value.

THE IMPORTANCE OF THE VALUE OF INFORMATION IN SUSTAINABLE AGRICULTURE

Farmers need to make a variety of complex decisions to ensure the success of their operation. This requires them to consider their information needs, the costs and value of the information, alternative sources of information and decide which information is necessary to collect before making a decision (Fountas et al., 2006). Financial benefits can be used as leverage points to help farmers change their management decisions and influence the overall sustainability of the farm system (Meadows, 2008). Improving best management practices for farmers relates to the Iowa Nutrient Reduction Strategy because it can improve the value of manure as a fertilizer and reduce the amount of nutrients that get lost to the environment.

Determining the value of information is very complex because all farms are different, however it can provide a good starting point for how farmers could receive benefit from different practices and provides an example of how the practice could be implemented into their production systems. Meadows (2008) explains that information holds systems together and plays a role in determining how they operate. One important idea related to decision

making is called the value of information. This concept as it relates to agriculture is the amount a farmer would be willing to pay for a specific piece of information before making a decision (Beherens et al., 2007).

It has been recommended that farmers test their manure for nutrient content for many years but adoption has been low. Magdoff et al. (1997) explored this problem: “the soil testing process and the complexities and pitfalls of recommendation systems are poorly understood by farmers as well as by many agricultural professionals....One of the main factors influencing farm decisions affecting nutrient flows is the perceived economic benefits of particular management options.” Helping farmers better understand how this information can be used can improve their nutrient management systems. This is especially important for managing animal production systems because manure nutrient content can vary from year to year.

Having information can affect farmer’s management decisions, which can affect their impact on the environment. Adding an economic factor can also influence their decisions. For this reason, it is possible that demonstrating to farmers that manure testing can be financially beneficial can lead to higher levels of adoption, which can be environmentally beneficial. Manure testing has been recommended to ensure that farmers are applying the correct amount of nutrients to their fields. Over application can cause nutrients to be lost to the environment, while under application can result in lower yields. For this reason, there is a need to optimize the value of manure for fertilizer use while ensuring that it is managed correctly to reduce negative environmental impacts. Because every livestock production and manure management system is unique, the best way to assess manure nutrients is by sampling and analyzing the manure at a laboratory. This testing comes with an added cost;

however, the use of the value of information can help farmers determine how much value a manure testing program can add to an operation. This example could be extended to a variety of recommended best management practices, such as soil testing, cover crops and conservation tillage, so it is important that scientists continue to work to develop models to provide a more accurate representation of the value of management practices to address some of the other challenges associated with improving sustainable agriculture.

Using the approach of general systems thinking by looking at agriculture as a whole instead of focusing on specific parts could help scientists understand the patterns underlying a diversity of situations such as nutrient management. Farley et al. (2008) brings up the point that people respond better to carrots than to sticks, implying that if people see the benefit to something, they will be more likely to do it than if there was a penalty for not doing it. This is another reason why economic incentives are beneficial because farmers can see the benefit rather than being afraid of potential regulations in the future.

CONCLUSION

In conclusion, although the focus of this paper was the aspects of the importance of economics in sustainable agriculture and the importance of information in sustainable agriculture, there are many additional challenges facing modern agricultural production. It is important for people involved with academic research to develop a better understanding for some of the more interdisciplinary aspects of agriculture to help determine how their actions affect other aspects of the world. Contributions from people from a variety of disciplines are necessary to develop long-term sustainable solutions to the agricultural challenges we face today.

Developing a better understanding of the social aspects between farmers and scientists can improve relations. This can help achieve a balance of production agriculture with sustainability. In addition to developing recommendations for farmers, scientists should provide recommendations on how the information could be of value to the farmers who they are trying to help. Improve and develop best management practices for manure to reduce negative impacts on the environment and increase profit for the farmer. Interdisciplinary work can improve agriculture as a whole, a necessary step in the right direction.

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CHAPTER III

WHAT IS IT WORTH?

THE ECONOMIC VALUE OF MANURE TESTING

Modified from a paper published in *The Transactions of the ASABE*

K.B. Regan and D.S. Andersen

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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.*

INTRODUCTION

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 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 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.

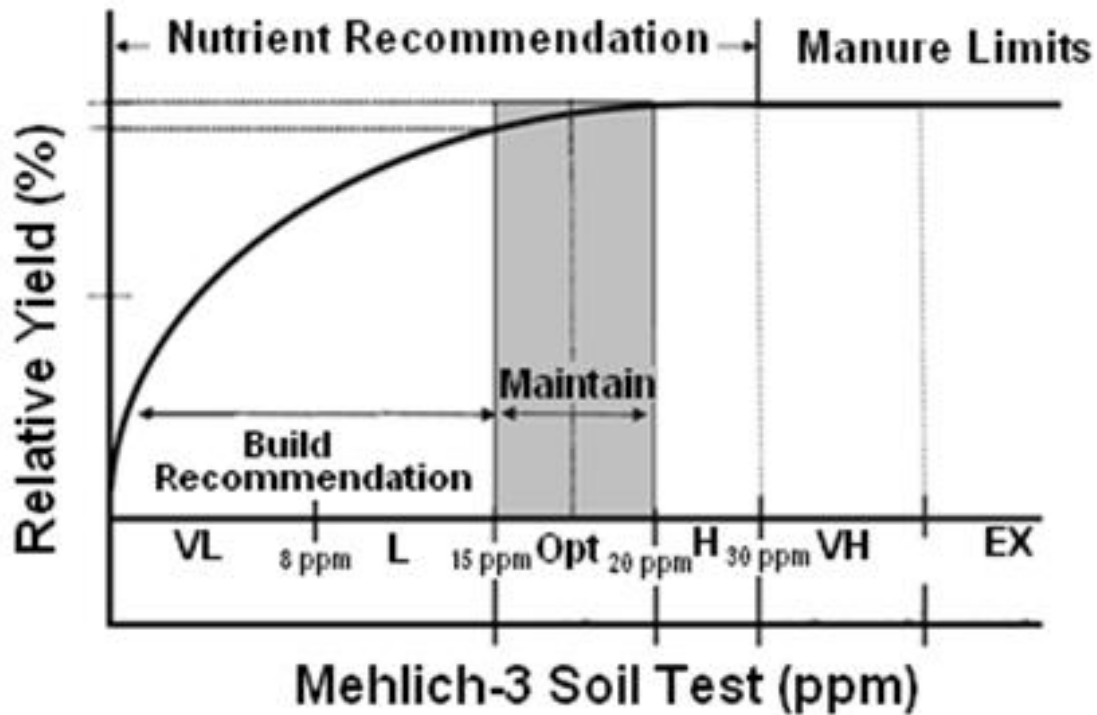


Figure 1. Conceptual schematic of crop response to soil test phosphorus level (based on Dodd and Malarino, 2005).

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.

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

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 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.

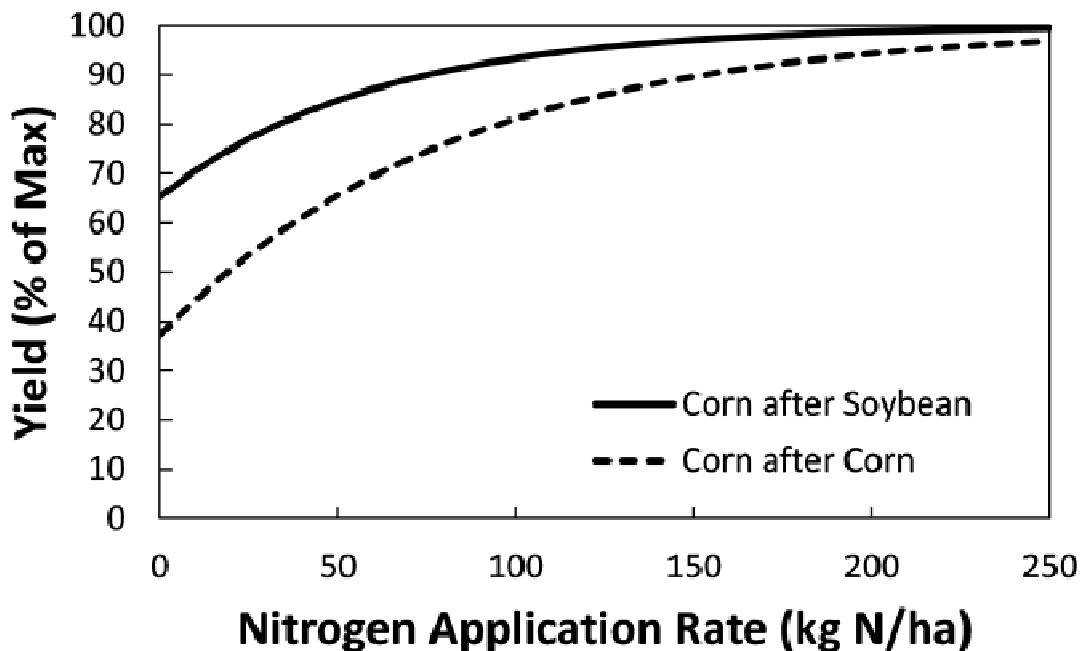


Figure 2. Yield response curves of corn to nitrogen application for corn after corn and corn after soybean rotations (based on Sawyer et al., 2006).

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

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% \pm 0.16% N with 0.21% P for deep-pit swine manure, 1.85% \pm 0.55% N with 0.60% P for layer manure, 0.30% \pm 0.12% N with 0.13% P for dairy slurry, and 1.18% \pm 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-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.

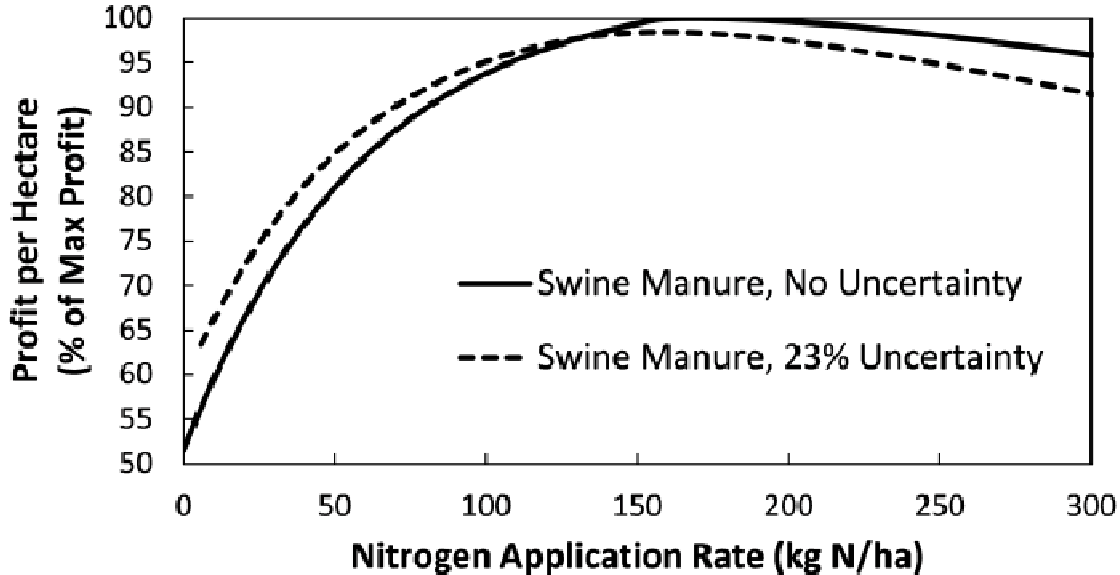


Figure 3. Effect of nitrogen application rate and uncertainty in manure nutrient content on profitability (uncertainty represents the coefficient of variation)

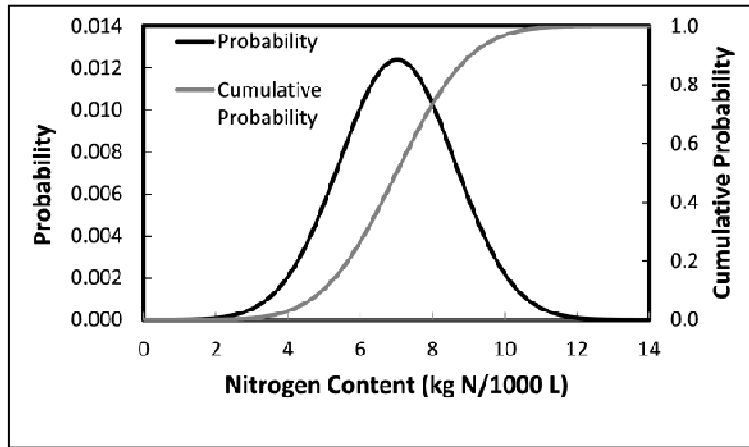
In practice, two methods exist for sampling and testing manure. The first method is to sample the manure before application so that the test results can be used to select the application rates. The second method is to sample the manure during application and use the test results afterward to verify the 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

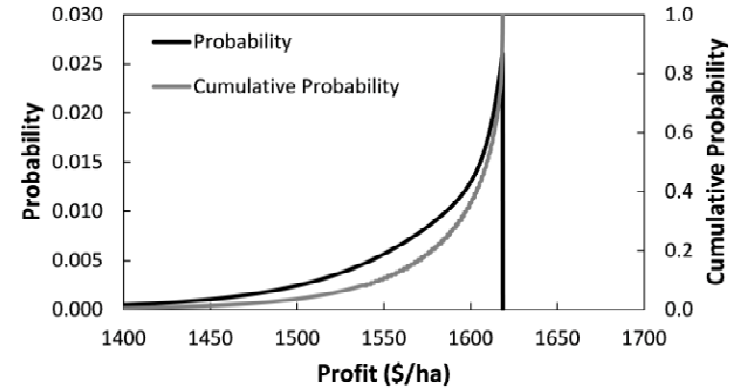
additional storage time, agitation, transport, and land application may have caused, making the sample more representative. A limitation of this method is that the results are not available to calculate the ideal manure application rate at the time of application and can only be used to validate the 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 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

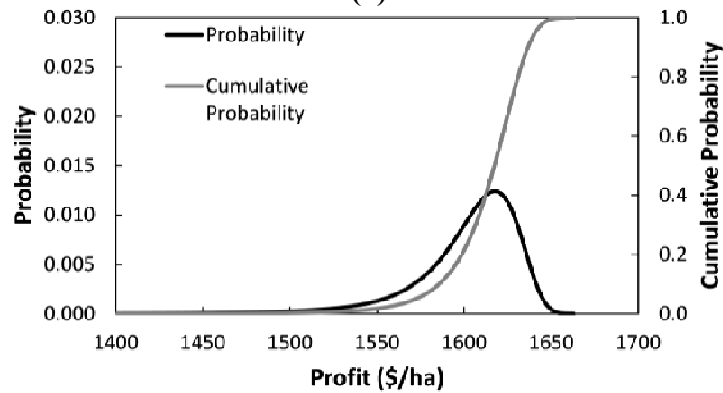
manure application was hydraulically limited, supplemental N was provided to achieve the MRTN application rate if supplemental N application increased profits.



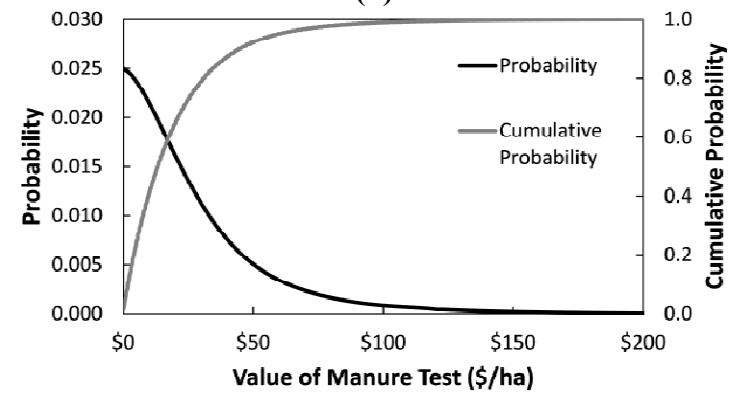
(a)



(b)



(c)



(d)

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).

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	Rotation	Pre-application		During application	
		N limited	P limited	N limited	P limited
		\$ ha ⁻¹			
Swine Slurry	Corn-Soybean	\$19.94	\$22.09	\$3.38	\$22.07
	Corn-Corn	\$30.66	\$10.62	\$8.37	\$10.62
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.

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		Beef Manure Sampled at	
		N-Limited Application		P-Limited Application	
		CS	CC	CS	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

DEMONSTRATION

These theoretical concepts were applied to a swine farm 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% \pm 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.

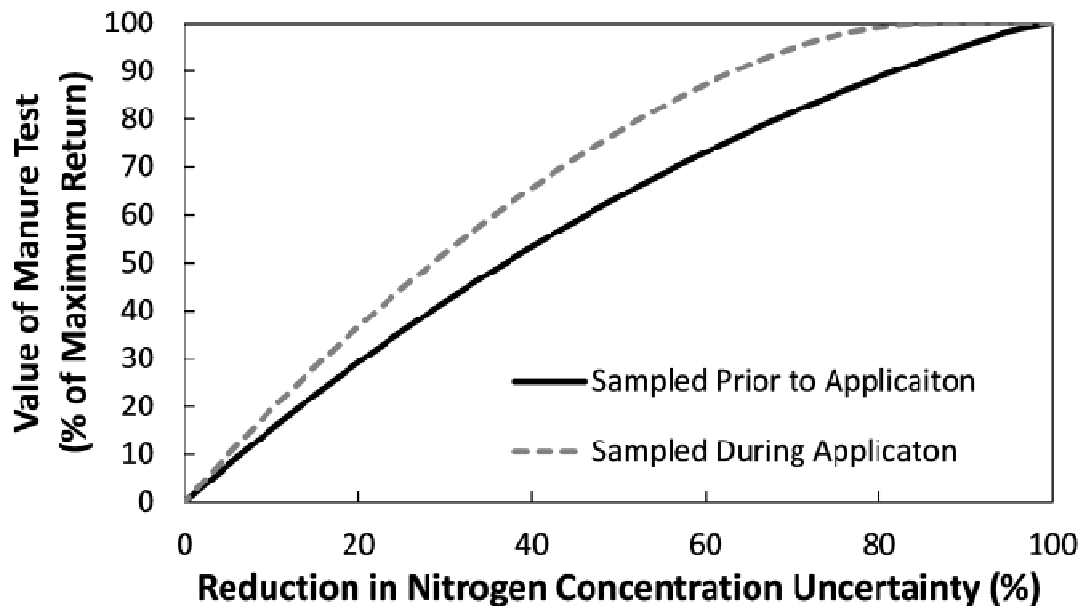


Figure 5. Evaluation of how imperfect information (i.e., remaining uncertainty in manure nitrogen content) impacts the value of the manure test for manure sampled before application at an N-limited rate and for manure sampled during application at a P-limited rate. Example calculations are for deep-pit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

THE IMPACT OF MANURE TREATMENT ON AMMONIA, GREENHOUSE GAS AND
ODOR EMISSIONS

Kelsey B. Regan

AN OVERVIEW OF ANIMAL PRODUCTION AND MANURE MANAGEMENT

The Midwestern United States has seen an increase in larger farm sizes as demand for animal protein has increased. Farm operations have implemented confined animal feeding operations to increase production with the economy of scale. In addition to these changes, there has been a demand for increased sustainability in agriculture, especially as it relates to greenhouse gas mitigation, odors reduction, and improved nutrient use efficiency and management.

Swine manure has always been used as a fertilizer for crop growth, however in the Midwest, there are limited times during the year that manure can be applied to fields due to weather and planting and harvest timing (Hatfield et al., 1998). In order to collect manure for use during these application times, storing manure for six to twelve months is necessary. One potential problem with long-term storage is that it can result in odors as well as ammonia and greenhouse gas emissions from the manure reducing fertilizer value, impacting barn air quality if manure is stored within the building, and leading to concerns from neighbors about potential impacts to their quality of life.

Emission of nitrogen, sulfur and odor from swine production systems occur from three main areas; the animal housing, the manure storage, and land application of the manure. Numerous manure management and land application practices (rate, timing, method of application, etc.) have been researched for reducing nutrient loss and odor (covers, anaerobic

digestion, composting, aeration, etc.), but as of yet implementation of these practices have predominately occurred only in the land application area. A study by Harper et al. (2004) found that NH_3 emissions occurred in the following quantities at different stages of manure storage as percent of total nitrogen excreted: animal housing (7%), manure storage lagoons (8%), and fields after manure application (2%). Although there is room for improvement with all aspects of manure management, there is especially a need to improve manure storage. It is important to follow best management practices for all stages of manure storage and handling, however the potential problems with the storage of manure is of particular concern because emissions occur continuously throughout the storage time, so potential problems are a daily issue. Various manure management practices exist to address these problems; however, lack of information on effectiveness of these practices can create confusion for farmers over the best to practice to implement. For this reason, this literature review will focus on manure management practices for swine manure storage that have the potential to reduce air quality concerns and nutrient management issues.

Evaluating the most feasible and economic ways of limiting nutrient and odor emission from manure storage at swine facilities will help producers better take advantage of their manure nutrients and limit the impact of swine production on air quality. The swine industry must be proactive in adopting and promoting practices that are both economically feasible and environmentally effective to reduce environmental concerns and avoid future regulation. Providing producers with information that is applicable to their operation will help them to make informed decisions to best utilize the nutrients in their manure as well as improve air quality for animal and workers at these facilities. This literature review will focus on the potential negative effects of manure emissions as well as some solutions that are being considered to address them.

EMISSIONS FROM LONG-TERM MANURE STORAGE SYSTEMS

Long-term manure storage has the potential to negatively affect air quality and nutrient management. Emissions are caused by biological activity within the manure while it is stored (Chadwick et al., 2011). There are three main types of emissions that can be a problem with manure storage including greenhouse gases, ammonia, and odors. The following sections will describe some of the potential negative effects of these emissions.

GREENHOUSE GASES

Recent concerns about the effect of greenhouse gases on climate change could result in regulations for animal production. Greenhouse gasses can be a problem because of their effect on climate change. Greenhouse gas emissions from manure include methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂) (Johnson et al., 2007). Methane and CO₂ are produced by the anaerobic breakdown of organic materials in the manure, while N₂O is produced through either nitrification or denitrification. It is believed that most N₂O is produced through incomplete denitrification, which is the step in the N cycle, in which nitrate (NO₃⁻) is reduced to nitrite and nitrous oxide (N₂O) and then hopefully further reduced to nitrogen gas (N₂) (Zerulla et al., 2001). However, it is also produced by autotrophic nitrifying bacteria oxidizing ammonia.

It is estimated that worldwide livestock production accounts for 14.5% of all anthropogenic greenhouse gas emissions (FAO, 2015). In 2009, the U.S. set the goal of reducing greenhouse gas emissions by 25% of 2008 levels by the year 2050 (EPA, 2012). This will require greenhouse gas reductions from a variety of sources; however, reduction from animal production systems can play an important role in achieving this goal.

AMMONIA

Nitrogen is present in manure in a variety of forms, but the form that is most likely to be lost during storage is ammonia, as since it is volatile, it can be lost through emissions. In Iowa, as

well as other areas where there is large-scale animal production, manure is commonly used as fertilizer to supply nitrogen to crops. Therefore, effective N fertilizer management is necessary to maximize nutrients available to crops, and nitrogen lost during storage represents a reduction of this fertilizer value

Livestock production is one of the largest emitters of ammonia to the atmosphere (Argo et al., 2001). A large percent (10-70%) of the nitrogen in the ammonia form can be lost when manure is stored over long periods of time, as is typical of current manure storage systems. It is difficult to quantify how much ammonia can be lost on a specific farm because many management and environmental factors can contribute to the rate of volatilization. Chadwick et al. (2011) estimated that manure slurry can lose about 33% of nitrogen from NH_3 emissions, while Argo et al. (2001) estimated that $0.3 - 9.0 \text{ g NH}_3\text{-N/m}^2$ is lost per day from deep-pit swine manure storage. Liu et al. (2014) found that deep pit swine houses emitted on average $3.57 \pm 2.00 \text{ kg NH}_3/\text{pig}$ per year. Nitrogen is a valuable fertilizer for crop production, so it is important that as much ammonia is retained in the manure as possible to increase the value of the manure as fertilizer. Increased N content can result in improved yields of crops when applied to the land (Castellano, 2010).

ODORS

CAFOs can be the source of offensive odors resulting from the emissions of ammonia, hydrogen sulfide and volatile organic compounds. Zoning of CAFOs and climate factors can transport these odors to areas where they can affect people who are not involved in livestock production. Odor can also have a negative effect on housing prices near CAFOs. Palmquist et al. (1997) found that proximity of the CAFO to a residency caused statistically significant reduction in house prices within a mile of the CAFO of up to 9% depending on the number of hogs and their distance from the house. Regulations were implemented in North Carolina that new swine

facilities must have Environmentally Superior Technologies to address odor and environmental problems (Schiffman and Williams, 2005). For this reason, investing in technologies that reduce odors could be economically valuable to avoid future regulations.

MANURE TREATMENTS

The management practices used by the farmer can affect the amount of emissions from the manure (Chadwick et al., 2011). Many technologies and practices exist to address the potential problems with long-term manure storage listed above however they vary in effectiveness, so farmers must choose a practice that fits their system and price range as well as provides an acceptable level of mitigation. Mitigation practices that are currently suggested for CAFOs include acidification, aeration, anaerobic digestion, composting, diet manipulation, permeable and impermeable covers, landscaping, manure additives, sitting, solid separation, and urine/feces segregation (McCory and Hobbs, 2001; Van Horne et al., 1994). Practices can vary in effectiveness, cost, and applicability for the producer and different practices work for different farms. Though different techniques have been developed for the mitigation of emissions, there is still a demand for new, cost-effective technology, which can aid in control. For example, diet modification to reduce protein in the animal's diet can improve nitrogen use efficiency and reduce the amount of nitrogen emissions from the manure; however, farmers may not have access to affordable feed with these characteristics (Chadwick et al., 2011). Although there can be some challenges to adopting practices to combat emissions, there can be economic, environmental, and health benefits to humans and animals when appropriate treatments are adopted.

BENEFITS OF MANURE TREATMENTS**Economics**

Cost margins for large-scale crop and livestock farms are tight; however, increases in fertilizer price are making swine manure a valuable commodity throughout the Midwest. The relatively high levels of nitrogen in swine manure and the increasing costs of purchasing inorganic fertilizers has renewed interest in better utilizing nutrients within manure. These economic changes offer opportunities to reevaluate manure management practices for changes in their feasibility. For instance studies have shown that losses of N during manure storage can range from 10 to 80 percent of the excreted amounts. Identifying technologies and management practices that improve the availability or utilization of manure nutrients can help producers increase profits by obtaining the full value of this by-product of swine production.

In addition to the potential to increase fertilizer value from treating manure, there could also be a value to reducing manure odors. This is because odors from animal production in concentrated areas can have a negative impact on the quality of life of people who live in areas where there is a large number of CAFOs. Although manure odor can be quantified and the demand for odor reduction has increased, the value of odor reduction is unknown.

Environment

From an environmental standpoint, increased implementation of effective best management practices for manure storage and land application are critical for long term sustainability of the swine industry. Different best management techniques vary in their effectiveness to address the potential impact of manure on air quality. Identifying and evaluating manure management techniques for the swine industry will help producers plan for the future and stay ahead of air quality concerns on the horizon.

Human Health

Manure emissions can be harmful both to the people who work in an animal confinement, the surrounding community and the animals themselves. One major effect of odors is the possibility for a negative effect on human health. Schiffman and Williams (2005) cited asthma like symptoms, headaches, sinusitis, nasal and throat irritation, muscle aches and pains for people living near CAFOs as well as acute and chronic respiratory impairment of workers in swine facilities.

Animal Health/Productivity

High levels of H₂S are released from manure if it is agitated, as is the case when manure is pumped out of the pit for land application and this can cause death of animals and danger to human workers (Donham et al., 1982). CO₂ from manure can cause asphyxiation and animal death in a matter of hours if the ventilation system fails (Donham et al., 1982). Loss of animals is a significant economic loss to farmers, so maintaining good air quality in the buildings is essential to improving the productivity of the farm.

TYPES OF MANURE TREATMENTS

Manure can be treated in three different ways with manure treatments falling into the following classifications: mechanical, biological and chemical. The following sections will consider some of the more effective treatments in each category and how they might be effective at reducing emissions from manure storage.

Mechanical

As the largest part of the manure slurry is water, it is natural to consider using a manure separating system to partition the nutrients in the slurry into different fractions. This could allow manure nutrients to be transported farther away from the farm. One fraction would be nutrient

dense and could be more economically transported away from the animal production facility, and the other fraction would have a low nutrient content that would be applied at high rates on land nearby the production facility. Potential economic benefits associated with an improved nutrient partitioning technology could potentially include reduced transport and land application costs, smaller manure storages (if a system where the low nutrient fraction could be irrigated onto the land more frequently could be developed), reduced odors, or potentially the recovery of a bedding product that could be recycled for on farm use (Hjorth et al., 2010). Hjorth et al. (2008) found that odors were reduced when manure was anaerobically digested before separation, but there was no significant effect on odors without anaerobic digestion; however, ammonia emissions from the liquid portion of separated manure were lower than unseparated manure.

Implementing a manure separation system would be a large initial cost to the farmer and would require significant manure management changes. Little information is available about the economics of implementing a manure separation system on a typical Iowa farm so more work should be done to evaluate the economic constraints on manure partitioning systems to reduce the costs of land application of manures and their effectiveness at reducing emissions on a typical Iowa farm. Additionally, this type of evaluation would allow producers to evaluate how a nutrient partitioning system would fit on their operation and the costs/performance combinations that would make these systems a successful part of their manure management.

Biological

Biological treatments can be systems such as anaerobic digesters, which break down manure components using anaerobic bacteria, or manure additives, such as microbes that are used to speed the decomposition of specific components of manure to reduce the loss of odorous compounds from the manure. Microbial additives are typically a mix of enzymes,

microorganisms, mixtures of trace minerals and carbon sources, or some combination of the three that are added to the manure at set intervals. Microbes in these mixes were often selected to perform specific functions; however, these microbes must compete with existing microbes within the manure, so it is difficult to know if they will survive and be effective. Another biological option is to add enzymes to the pit or the animal feed. Enzymes are selected to break down certain types of solids in the manure, such as cellulose or proteins, which is typically harder to break apart.

Treatment with Anaerobic digestion

The adoption of anaerobic digestion systems has been suggested to mitigate methane emissions from manure storage and production of renewable energy (Clemens et al., 2006). Bacteria are used to breakdown organic material in the manure to produce methane. This methane is captured and stored for future energy use. In addition to reducing greenhouse gas emissions, Powers et al., (1999) found that reduction of odors was possible because anaerobic digestion in a continuously stirred reactor reduced odor intensity linearly with increasing hydraulic retention time up to 20 days and fixed-film digestion with 1.5 or 2.3 day hydraulic retention time reduced odor intensity similarly to that observed with 10 day hydraulic retention time in a continuously stirred reactor. In their study, a 20 day hydraulic retention time decreased odor intensity scores by approximately 50% in the continuously stirred reactor, and odor intensity also was reduced, but to a lesser extent, in the shorter hydraulic retention time fixed-film digesters. Powers et al., (1999) found that prescreening of the feedstock significantly reduced ammonia N concentration in CSTR digesters and ammonia N concentration was affected in curvilinear fashion with hydraulic retention time.

Although anaerobic digestion can be effective at reducing emissions, there are significant economic constraints and this can limit the ability for a farmer to invest in this system. Faulhaber et al. (2012) found that there was an economy of scale for anaerobic digestion to be economically viable and interest rates of investing in a system had a large impact on the economics of the system. She developed a model that determined that anaerobic digestion could be economically viable for dairy farm sizes greater than 1000 cows as the interest rate approaches 1%. The economics of anaerobic digestion are also related to carbon values; however, these change based on the price of commercial energy in the US so it is difficult to determine the economic effect of a long-term investment in anaerobic digestion when only carbon credit values are considered because these change based on energy prices. Given the \$20 Mg⁻¹ carbon credit prices that have been suggested in the by Faulhaber et al., (2012), the use of AD to achieve the U.S. Secretary of Agriculture's GHG emissions reduction goals appears economically viable if natural gas prices are sufficiently high.

Faulhaber et al. (2012) suggests that digester costs can be reduced in the following ways: improved structural design to reduce actual digester construction costs without sacrificing longevity and reliability, improved structural design to increase expected lifetime and thereby lengthen amortization period, provision of low-cost loans or matching funds for digester construction, improved bioprocess engineering to enable equal degradation at lower retention times (thus decreasing reactor size and cost while maintaining gas production. However, even with these changes implementation on swine farms would require substantial modification to our current swine manure systems as manure would have to be collected and moved to the digester quickly after excretion to capture the maximum energy content and reduce odor potential.

Moreover, alternative storage that does not return the manure to within the barn would presumably be required.

Biological inhibitors

Another possible method that might have the potential to reduce greenhouse gas production is adding a product directly to the manure storage pits that reduces microbial activity. Biological inhibitors use additives to temporarily decrease the rate at which biological processes that produce emissions occur, such as preventing the formation of N₂O from nitrification or the formation of CH₄ from methanogenesis (Zerulla et al., 2001).

One product that has been tested in the lab setting for its potential to reduce gas production from swine manure is tannins (Whitehead et al., 2012). Similarly, others have recommended the use of Rumensin as a pit additive to reduce foaming (Clanton, 2012). However, Rumensin has been reported to be toxic to pigs if consumed (lethal dose of approximately 16 mg/kg) so this is a risky proposition. Another ionosphere, Narasin, is safe for swine. Narasin has been shown to be effective in small batches of manure, but it has not been tested in a continuous flow system (Andersen and Regan, 2014). For this reason, it will be necessary to evaluate if addition of Narasin to swine manure would reduce methane and biogas production from the manure and if so, what dosing rate of Narasin would be required to achieve reduction.

Enzymes/microbial additives

The breakdown of organic material in manure can cause odors. The majority of these odorants are a result of incomplete digestion, or intermediate products like endols, skatoles, cresols, alcohols, and volatile fatty acids. Ultimately, the final compounds of carbon processing,

CO₂ and CH₄, are odorless, thus adding microbes or enzymes to the manure to increase the rate of its decomposition to the final products could reduce odors by limiting the opportunity for the intermediate products to escape. There is limited information available on the effect of enzymes or microbial additives on manure emissions. One limitation to this method is that microbes need to be added frequently because they may not be able to naturally survive in the conditions of manure storage systems (Andersen et al., 2014).

Chemical

A large number of technology and management options are worth considering, however, upon review they may not all be considered effective or suitable enough for implementation at swine operations. Many techniques have been proposed to address the potential problems of manure emissions. Different techniques vary in effectiveness and cost. One of the main constraints that limit the implementation of different practices is that it can be difficult and expensive for farmers to change their management practices. Therefore, the possibility of using manure additives could be widely implemented by farmers if they are effective.

Chemical additives have been suggested to reduce odor and retain nutrients in manure (McCrorry and Hobbs, 2001; Shah et al., 2011). Additives can be supplemented to the feed, sprayed into air, or add directly to manure, with delivery method dependent on the product. Additives vary in effectiveness, but they can be relatively low cost, depending on dosing rate and frequency (McCrorry and Hobbs, 2001). Conditions vary from farm-to-farm, so it is difficult to know which manure properties will make each treatment more effective.

There are several types of additives that may have an effect on manure nutrient retention or odors, which fall into the following classes: pH modifiers and acidifiers, digestive additives, oxidizing agents, disinfectants, adsorbents, saponins from yucca, and masking agents and

counteractants (McCrorry and Hobbs, 2001). Most additives have an effect on only one type of emission and it is possible that it can decrease one type of emission while increasing the other (Shah et al., 2011). Each type of additive has different benefits and challenges associated with it.

Acid

Acidifying manure makes the ammonia less volatile because more acidic conditions favor the ammonium form of nitrogen which is not volatile. Several lab-scale studies have shown that acidifying swine manure can result in ammonia loss reductions from 50% to 85%, depending on the pH achieved (Vandre et al., 1997). Reducing ammonia emissions could have an economic value to the farmer in terms of improved swine performance due to better air within the barn and increased nitrogen content in the manure. When acid was used in swine production, Jensen (2002) found that swine growth rate improved at a rate of 115 g/day and Kai et al. (2008) reported an increase of 22 g/day. Kai et al. (2008) also found that mortalities decreased by 9 deaths per 1000 pigs. The exact costs and benefits of adding acid to manure are not well understood; however, improvements in swine production and nutrient value of manure could potentially make the cost of purchasing acid economically feasible.

Sorbents

Several types of sorbents have also been suggested because they function by binding odorous compounds on their surfaces. Adsorbents can come in natural forms such as clinoptilolite (a type of zeolite, silicate material), Sphagnum peat moss, as well as chemical organic polymers that are designed to maximize sorption. Studies that used zeolites for odor control have reported varied results on effectiveness. It is unknown which manure characteristics make it work, how long it will be effective or how it will work in a deep-pit manure storage system. Clinoptilolite are a type of zeolites that act as an adsorbent because they have a high

affinity for NH_4^+ ions, so they can bind ammonium and reduce ammonia volatilization when added to a deep-pit. Miner et al. (1997) found that application of 1 to 4% clinoptilolite to dairy slurry immediately before surface application reduced ammonia emission by 60%. Similarly, the high adsorption capacity of these compounds can reduce odor emissions. A study of zeolites as an amendment for poultry litter recently demonstrated a 50 to 70% reduction in odorants from the manure (Cai et al., 2007); however, McCrory and Hobbs (2001) reported zeolite would likely have limited effect on odors from manure slurries. One potential problem with the use of zeolites is that increased total solids in the manure may change its handling characteristics.

Another way to use zeolite could be to use it in an air scrubber. Koelliker et al., (1980) used zeolites in an air scrubber to treat manure odors and found that the use of a single stage scrubber demonstrated that clinoptilolite has an ability to adsorb NH_3 directly from the air within a laying house as well as a desirable capability of removal of NH_3 upon contact with laying house air. The device removed from 15 to 45 % of the $\text{NH}_3\text{-N}$ from the air that passed through the system. Due to limited information on the effectiveness of zeolites, more research should be done to determine if zeolites can be effective at reducing manure odor in a swine facility, specifically by testing zeolite addition with manure that has different properties to develop a better understanding of which properties it works with to determine how long zeolite can be effective in order to develop a recommended dosing rate.

Another type of sorbent that has been suggested is acidic copolymers, which have the advantage of combining the benefits or modifying manure properties through sorption and acidification. The developers of a product that uses an acidic copolymer, called More than Manure, claim that it is “The first and only manure manager proven to reduce: Nitrogen loss from leaching, volatilization and denitrification, Phosphorus lock-up”, however research with

similar products has had mixed results, especially with phosphorus stabilization. When used as a urease inhibitor, Chen et al. (2014) found that laboratory incubation studies showed that the copolymer is not a urease inhibitor at all and the rate of urea hydrolysis was not reduced by the copolymer as compared with that of urea alone. When used to prevent ammonia volatilization, Chen et al., (2014) found that results from urea treated with and without the copolymer did not differ, indicating that the copolymer did not reduce NH_3 volatilization from urea in Renshaw soil and the copolymer actually enhanced NH_3 volatilization of urea compared with urea alone, probably due to the stimulation of urease activity by the copolymer. Due to limited information on the effectiveness of acidic copolymers, further testing should be done to determine if their use should be recommended as a best management practice to reduce manure odors and stabilizing nutrients by testing acidic copolymer effectiveness in a continuous flow system to model the effectiveness in a barn setting.

Oxidizers

The use of oxidizers has been suggested to destroy specific bacteria that reduce emissions. Several chemical oxidizers have been shown to be effective including oxygen, chlorine, potassium permanganate, hydrogen peroxide, and ozone; however the amount that would need to be added to achieve desired reductions in manure emissions would be cost prohibitive (Watkins et al., 1997). Another type of additive is soybean peroxidase (Koziel et al., 2014; Maurer et al., 2015). Parker et al. (2012) found that soybean peroxidase when used with CaO resulted in a decrease in the VOC 4-methylphenol by 98% after 24 hours and 92% after 48 hours in swine manure.

LIMITATIONS OF MANURE TREATMENTS

COST

More research needs to be done to compare the costs of different manure treatments based on the management constraints of typical farms. Some treatments such as manure separation or anaerobic digestion require a large initial cost but can be effective for a number of years, while additives can be relatively inexpensive for each individual dose but continuous dosing could accumulate costs. Economic evaluations should address the potential value of retaining manure nutrients and decreasing manure odors. Short- and long-term costs and benefits should be considered when deciding on which manure treatment to use.

MANAGEMENT CHANGES

It is predictable that farmers would be more likely to adopt manure treatments that can be easily implemented with their existing manure management practices and require less time and maintenance. New facilities or farmers that are remodeling existing facilities may be more willing to implement different manure treatment system. From a long-term standpoint, adoption or planned implementation of more effective manure management practices may be necessary to improve sustainability of the swine industry.

EFFECTIVENESS

One treatment is not effective for all types of emissions, so multiple treatments or technologies may need to be considered. A review of manure treatments found that increasing the pH decreased odors, but caused an increase in ammonia and hydrogen sulfide emissions (Zhu, 2000). Therefore, farmers must decide which emissions they want to mitigate and chose a treatment accordingly.

NEED FOR FUTURE WORK

The impacts of agriculture on air quality are under increased scrutiny and all parts of agriculture must respond accordingly. The swine industry has long recognized that manure can be a valuable resource, but there is potential for better utilization of manure nutrients. Pork producers need reliable information to make informed decisions about manure management and land application systems, especially if new technology is to be implemented. Further work is needed to help fill this information gap by providing information on techniques and technologies that farmers could use to determine the most appropriate options for their operations.

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CHAPTER V

EFFICACY OF MORE THAN MANURE TO REDUCE AMMONIA, GREENHOUSE GASES, AND ODORS FROM STORED SWINE MANURE

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INTRODUCTION

Iowa has one of the highest concentrations of Concentrated Animal Feeding Operations (CAFOs), ranking first in the nation for swine (producing about 1/3 of the nation's pork) and egg (producing about 17% of the nation's eggs) production as well as ranking highly for production of other sources of animal protein (beef, turkey, pork, eggs, dairy, etc) (USDA, 2015). This results in a large concentration of animal manure that is stored over long periods of time, which has the potential to, if not properly managed, cause several problems, such as negative effects on the environment, adverse impacts to human and animal health, and economic losses (Ndegwa et al., 2008). However, improved management practices and proactive approaches to managing these manure issues may be able to reduce the potential impact of these negative effects.

Emissions from livestock production include ammonia, hydrogen sulfide, methane, and odors. Odors and hydrogen sulfide can cause problems locally, while ammonia and methane have regional and global scale impacts on ecosystems (Flora et al., 2007). Swine farms in Iowa and throughout the country have been under increased pressure to control emissions (EPA, 2014). Nitrogen loss from manure can be an economic loss for swine farmers because when nitrogen is lost from the manure during storage, there is less available to recycle and use as fertilizer for crops. By finding a way to reduce losses of nitrogen through manure emissions, the sustainability of producing animal protein can be increased and the nitrogen use efficiency of the

system can be improved. For this reason, improved manure management can result in better air quality and less financial losses for the farmer. Figure 1 shows the cycle of nitrogen use in swine production. Losses can occur at various stages of production including storage (15-30%), land application (about 0%-2% with injection or 1-25% for broadcast application) and crop production (MWPS, 1993; Sawyer and Mallarino, 2008). Since manure storage accounts for a significant portion of nitrogen losses, reducing these losses could allow more nitrogen to be used for crop production, thus improving the nitrogen use efficiency of swine production.

Several options exist to retain manure nutrients and reduce odor. These options include separation, chemical additives, and anaerobic digestion, among others (McCory and Hobbs, 2001; Van Horne et al., 1994). Despite the fact of existing practices that are effective at reducing ammonia and odor emissions from manure storages, such as solid separation, and aeration, adoption is relatively low due to cost, effectiveness, or because they require drastic change to the manure management system. Chemical additives have been suggested to reduce odor and retain nutrients in manure (McCory and Hobbs, 2001; Shah et al., 2011). There are several types of additives that may have an effect on manure nutrient retention or odors, which fall into the following classes: pH modifiers and acidifiers, digestive additives, oxidizing agents, disinfectants, adsorbents, microbial inhibitors, and masking agents and counteractants (McCory and Hobbs, 2001). Most additives have an effect on only one type of emission and it is possible that it can decrease one type of emission while increasing the other (Shah et al., 2011). Each type of additive has different benefits and problems associated with it.

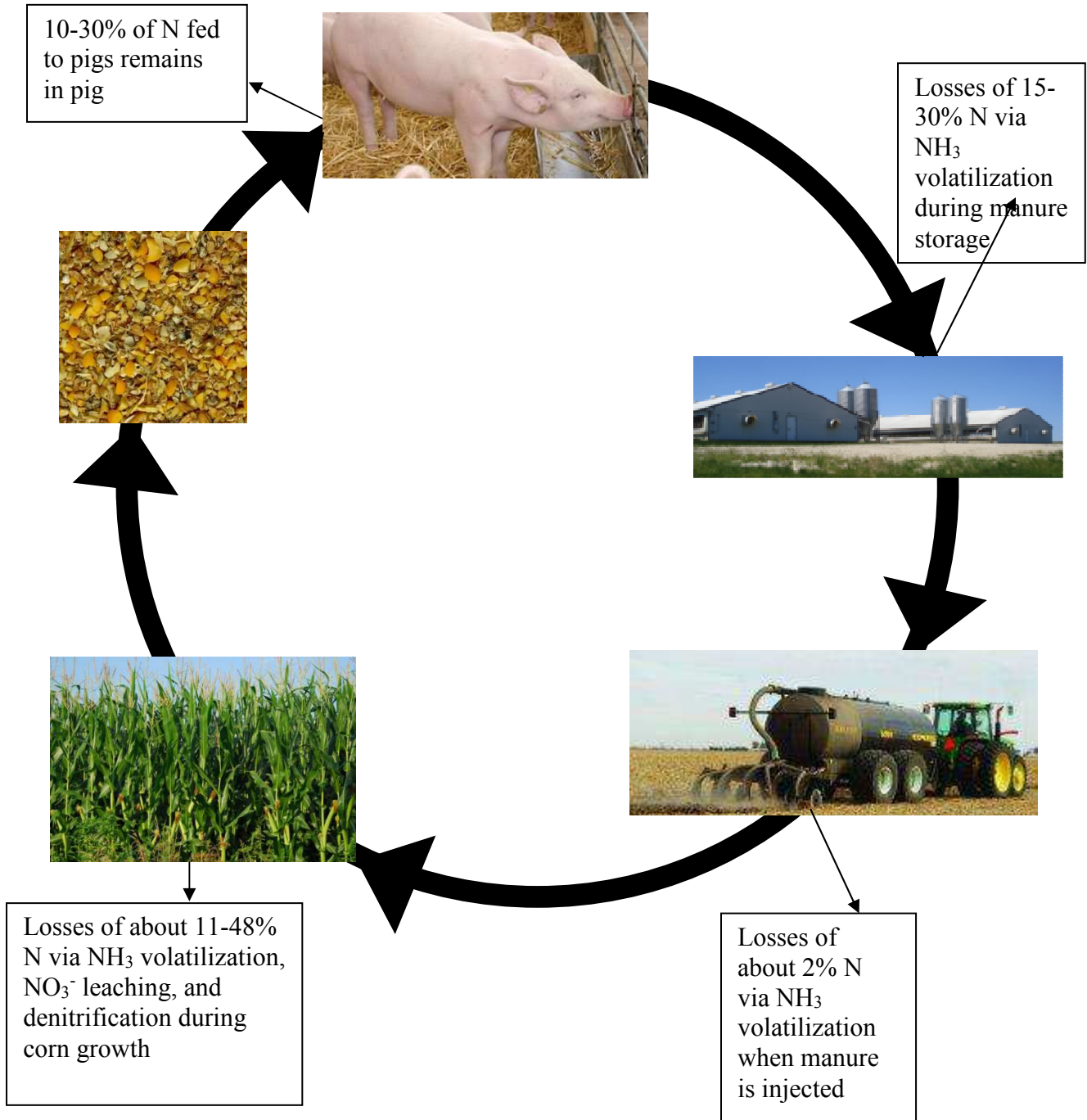


Figure 6. Swine production nitrogen cycling. Typical sources of nitrogen loss include volatilization during manure storage of 15-30% (Harper et al., 2004), volatilization during injection of 2% (Harper et al., 2004) and losses from field through volatilization, leaching and denitrification of 11-48% (Reddy and Reddy, 1993).

Manure acidification has been suggested because several studies have shown that it has the potential to increase nitrogen retention in the manure and improve air quality within the barn (Vandre and Clemens, 1997; Erikson et al., 2008). Manure pH can be lowered through diet modification or addition of acid to the manure, with the second option being more effective over long-term storage because a lower acidity can be achieved (Kai et al., 2008). Manure acidification has been shown to be effective with poultry litter, but implementation can be difficult for swine manure slurry due to the risk of handling and storing large amounts of acid on swine farms and the increased risk of foaming (Jensen, 2002). Some potential negative effects of using acid are the safety concerns to the user if concentrated acids are used and the fact that reduced pH is conducive to volatilization of hydrogen sulfide and other odorous compounds (Kai et al., 2008). Several lab scale studies have shown that acidifying swine manure can result in ammonia loss reductions from 50% to 85%, depending on the pH achieved (Vandre et al., 1997). The effect of manure acidification on odor has mixed results. A review of manure treatments found that increasing the pH decreased odors, but caused an increase in ammonia and hydrogen sulfide emissions (Zhu, 2000).

Several types of sorbent additives exist, including natural clay particles such as zeolite as well as synthetic additives such as organic polymers which bind to either ammonium or other particles with the correct charge in the manure. Sorbent particles with large surface areas can cause odors to react with the sorbent to hold the gasses before they are released from the manure (Andersen et al., 2014). Synthetic additives have the potential to be more effective at sorption than natural additives because their bonding sites can be tailored to allow for more sorption (Lu et al., 2007).

The developers of a product that uses an acidic copolymer, called More than Manure, claim that it is “The first and only manure manager proven to reduce: Nitrogen loss from leaching, volatilization and denitrification, Phosphorus lock-up” (SPF, 2014). Chen and Yadanaparathi (2013) found that higher doses of More than Manure led to lower manure pH and lower ammonia emissions when used with dairy manure. Their (Chen and Yadanaparathi, 2013) experiment evaluated the ammonia concentrations over a 24 hour period after adding More than Manure, but since manure is stored for up to a year on most farms, this study aimed to evaluate the long term effect of More than Manure. Academic studies have not evaluated the effect of More than Manure on swine manure, so this study aimed to evaluate its effect on a different manure type.

The use of an acidic copolymer is an option that requires little change to our current manure management paradigm, providing an opportunity to lead to high levels of implementation, but as of yet little is known about its effectiveness. At this point, only one study by Chen and Yadanaparathi (2013) has been published using More than Manure, but some studies have been done with AVAIL, which has the active ingredient of partial sodium salt of maleic-itaconic copolymer in 30% w/w, while More than Manure uses partial ammonium and calcium salt of maleic-itaconic copolymer in 40% w/w. When used as a urease inhibitor, Chien et al. (2014) found that laboratory incubation studies showed that the copolymer is not a urease inhibitor at all and the rate of urea hydrolysis was not reduced by the copolymer as compared with that of urea alone. When used to prevent ammonia volatilization, Chien et al., (2014) found that results from urea treated with and without the copolymer did not differ, indicating that the copolymer did not reduce NH_3 volatilization from urea in Renshaw soil and the copolymer actually enhanced NH_3 volatilization of urea compared with urea alone, probably due to the

stimulation of urease activity by the copolymer. Due to lack of information on the effectiveness of More than Manure on swine manure emissions, this study was developed to determine whether it had an impact and whether it would be cost effective. For this reason, this experiment evaluated the effects of More than Manure on crusted and uncrusted manures. The two different manure types were tested to evaluate the effect it could have over a range of manure conditions typical of deep pit systems.

The use of acidic copolymers has been suggested because it has a dual mode of action in which it acidifies and sorbs at the same time. Acidic copolymers are long carbon chain molecules that release acid when mixed with water. The acidification mechanism of the acidic copolymer additive can retain ammonia might convert the ammonia near the molecule into ammonium which can then bind with the more than manure. Alternatively, if it would float on the surface it could act as an acidifying on sportive barrier that ammonia being emitted from the manure is captured by. Therefore more N remains in the manure. Swine manure typically has a neutral pH, ranging from 7.51 to 7.74, (Van Weelden, 2014). The pH of manure tends to increase with storage, so reducing the pH can reduce volatilization (Andersen et al., 2014). One reason why a farmer might consider using an acidic copolymer is the ease of use and potential cost effectiveness over other options. Adding an acidic copolymer to the manure pit would not take any special equipment or require the farmer to make significant changes to their current farm or manure system.

Since previous studies have had mixed results on the effectiveness of synthetic sorbents and there is little knowledge on their long-term effect, the purpose of this project was to determine if their use should be recommended as a best management practice, especially for manure treatment. The next logical step is to evaluate if the mechanisms that reduce N loss in-

field can also reduce nitrogen loss during manure storage. Important opportunities exist to evaluate if this translates into (a) lower emissions of ammonia (NH_3) from swine manure deep storage pits and (b) lower concentrations of NH_3 inside swine barns at the animal breathing zone level. In addition, testing the effects of MTM on air pollutants and gases of concern originating from manure (H_2S , odorous volatile organic compounds (VOCs)), and greenhouse gases (CO_2 , CH_4 and N_2O) is important to comprehensively assess the performance of MTM. Therefore, the objective of this work is to evaluate the effectiveness of More Than Manure to reduce ammonia emissions from deep-pit swine finishing facilities and improve air quality in the animal environment by testing it at the pilot scale to compare its effects on treated and untreated manures, as well as to determine which dosing rate is most effective.

MATERIALS AND METHODS

PILOT SCALE SETUP

Swine manure was collected from two facilities with deep pit storage. One facility was located in Story County, Iowa and had an outdoor deep pit without a manure crust, which was used as the uncrusted treatment. The other facility was located in Marshall County, Iowa and had a deep pit below the swine barn and the manure had a crust. This manure was used for the crusted treatment. The manure was transported to the Iowa State University (ISU) ABE Livestock Environment and Building Research Center (LEBRC) located 9 miles from ISU campus near Boone, IA for pilot scale testing. The manure was pumped in to six and nine 1.22 m (4 ft) tall, 0.38 m (15 in) diameter sealed manure storage simulators respectively (Figure 7 and 8). Twenty-six liters (6.85 gal) of swine manure was added initially followed by 3.79 L (1 gal) weekly manure additions for 15 weeks after the first MTM addition resulting in a final volume of

75.14 L (19.8 gal). The simulated ventilation was controlled via rotameters in order to achieve a ventilation rate of 7.5 headspace air exchanges per hour. The rate was adjusted when fresh manure was added to keep the 7.5 headspace air exchanges per hour constant. Air exchange rates were consistent with typical values for air exchange rates of manure pit storage areas in swine barns with fully slatted floors (Harmon, 2013). Storage temperature was kept between 9 and 20 °C (average = 15.6 ± 3.7 °C) to simulate the temperature of deep pit storage (Andresen, 2013).

Baseline measurements were taken over 15 days prior to MTM addition in order to evaluate emissions from each of the 15 storage simulators so that the treatments could be randomized to eliminate storage simulator variation.

On day 15 of the trials, MTM was then applied at the recommended dose of 2 mL to three of the six non-crustrated manure simulators and three of the nine crustrated manure simulators. Three of the nine crustrated manure storage simulators received double the recommended dose of MTM which was 4 mL. Three of the non-crustrated manure simulators and three of the crustrated manure simulators did not receive MTM and were used as controls. On day 22 of the trials a 10 times the recommended dose of MTM was added to the crustrated manure storage simulators that had previously received the double recommended dose. On day 50 of the trials, all crustrated and non-crustrated treated manure storage simulators received a 10 times the recommended dose of MTM. The total duration of pilot experiment was 116 days with 101 days after the first MTM application. Manure samples were collected before MTM application on day 15, again on day 82 and again on day 115 of monitoring for analysis. Ammonia, H₂S, and relative humidity measurements were collected on selected 55 days after MTM application (approximately four times a week). Methane, CO₂, nitrous oxide (N₂O) measurements were collected on selected 17 days after MTM application (approximately once a week). VOC measurements were collected

on selected 7 days over the 101 day monitoring after the MTM application (approximately once a month, with more frequent sampling in the first two months).

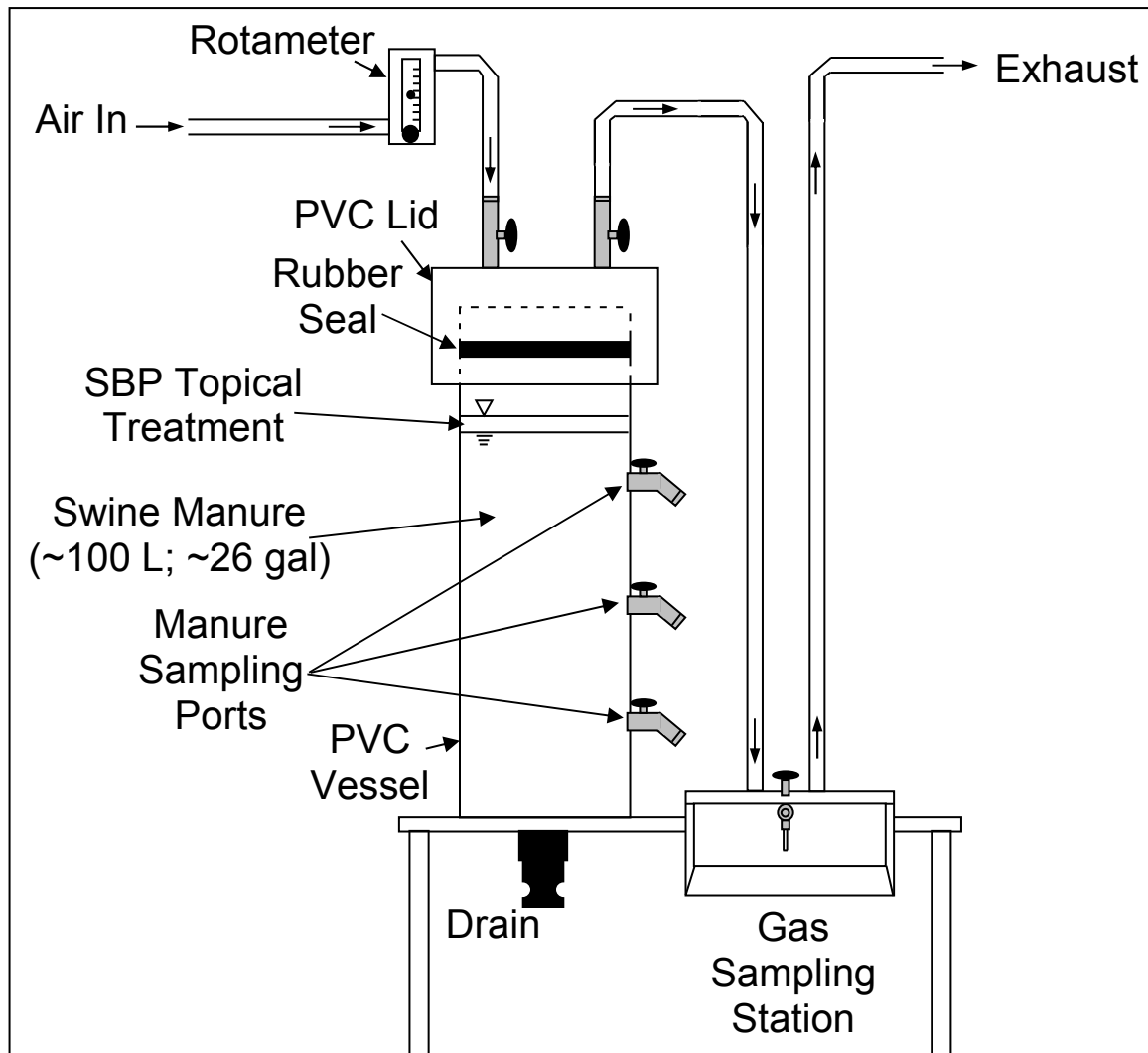


Figure 7. Pilot scale manure storage setup (Maurer et al., 2015).



Figure 8. Pilot scale reactor setup. Fifteen 36 gal PVC reactors to hold swine manure with adjustable ventilation flow control and emission sampling stations.

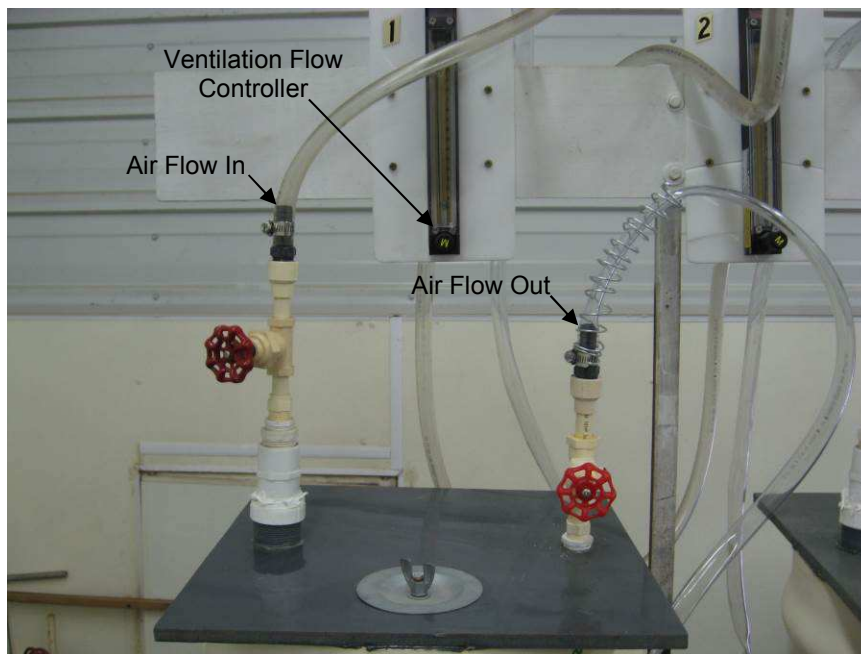


Figure 9. Pilot scale ventilation control and plumbing of each reactor. The air in is supplied via air compressor, the flow rate to each reactor is controlled via individual rotameters, and the air out flow is directed to gas sampling stations before being vented outside.

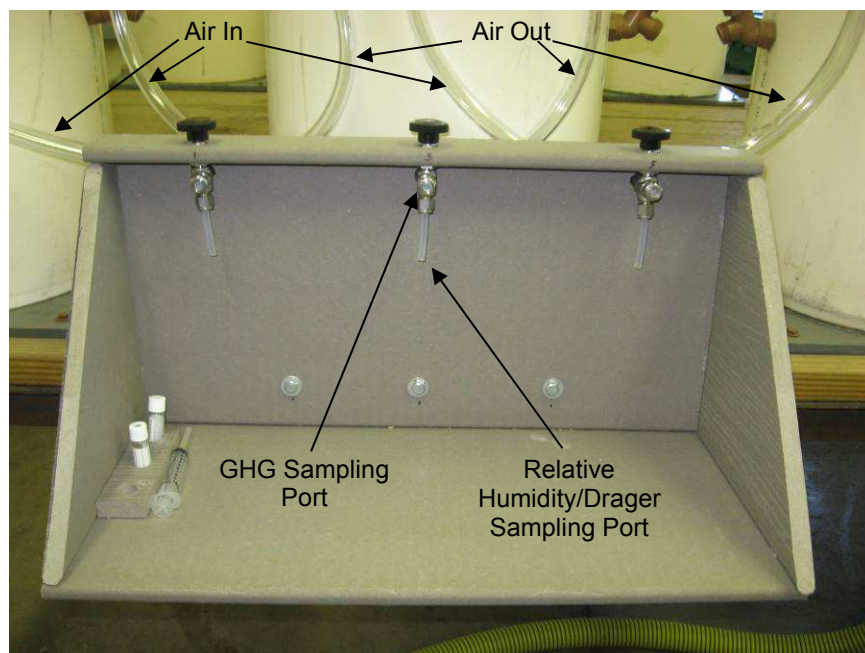


Figure 10. Pilot scale gas sampling station. Gas sampling stations were setup in the “Air In” venting emissions flow from each reactor with the ability to take gas samples for GHG analysis at any time and the ability to open a line in the vent stream to collect NH_3 and H_2S via the Drager analyzer or to collect VOCs via sorbent tubes.

RELATIVE HUMIDITY



Figure 11. Pilot scale gas sampling station setup for relative humidity. Sample pump pulls air from the reactor vent line through sealed tube containing relative humidity probe.

Percent relative humidity was monitored in order to calculate the emissions of standard air (Figure 5).

GREENHOUSE GASES

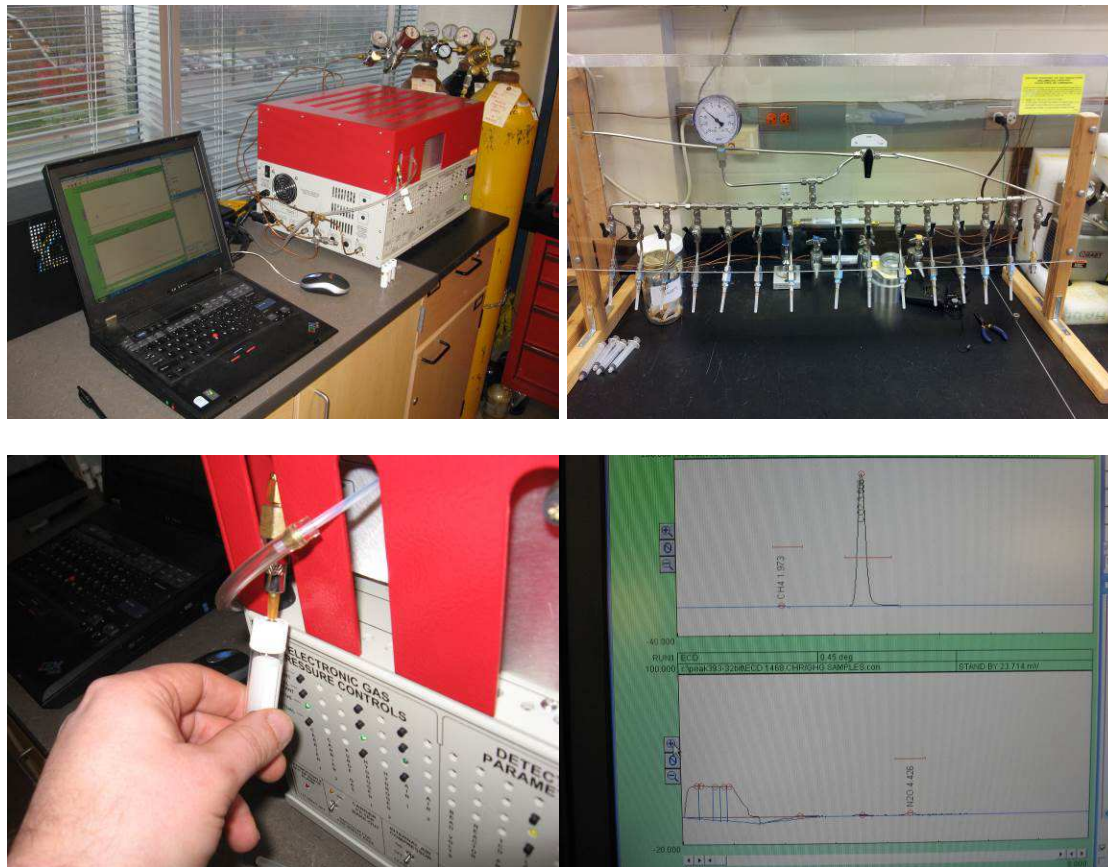


Figure 12. Top Left: SRI Greenhouse Gas GC. Top Right: Sample vial cleaning system. Sample analysis of GHGs. Bottom Left: Gas sample is injected on the GC. Bottom Right: Chromatogram of gas sampling showing CH_4 , CO_2 and N_2O .

Gas samples collected (Figure 8) in the field via syringe and 5.9 ml Exetainer vials (Labco Limited, UK) were analyzed for GHG concentrations on a GHG GC (SRI Instruments, Torrance, CA, USA) equipped with FID and ECD detectors (Figure 7). Gas method detection limits were 1.99 ppm, 170 ppb, and 20.7 ppb for CO_2 , CH_4 and N_2O , respectively. Standard curves were constructed daily using 10.3 ppm and 20.5 ppm methane, 1010 ppm, 4020 ppm and 8100 ppm carbon dioxide, and 0.101 ppm, 1.01 ppm and 10.1 ppm nitrous oxide (Air Liquide

America, Plumsteadville, PA, USA). Standards used for standard curve construction were done in duplicate for CH₄ and CO₂ while N₂O standards were done in triplicate. The conversions to gas concentrations (ppm) for the samples were based on peak area for CH₄ and CO₂ and on peak height for N₂O (peak height was a more consistent measure due to smaller peaks).



Figure 13. Pilot scale sampling station GHG collection. Left: GHG sample was collected from reactor vent line from pilot scale swine manure storage. Right: GHG sample was transferred to vial for transport to lab for analysis.

VOLATILE ORGANIC COMPOUNDS (VOCs)

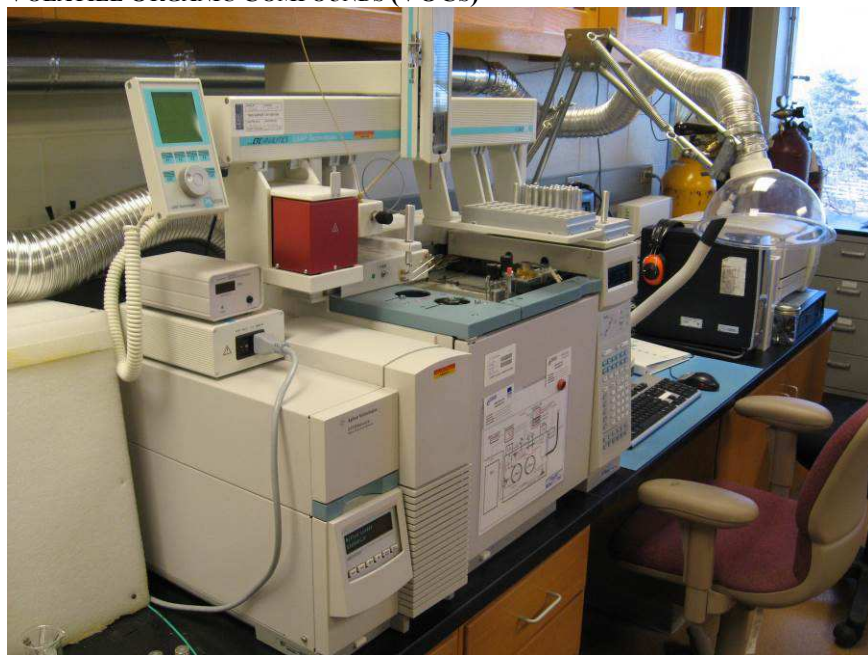


Figure 14. Thermal desorption - multidimensional gas chromatograph – mass spectrometer – olfactometer (TD-MDGC-MS-O) for VOCs analysis. Gas samples were collected on sorbent tubes in the field (e.g., reactor vent line or barn room exhaust fan), brought to the lab and

desorbed/introduced to MDGC-MS-O for analysis via thermal desorption (TD) autosampler. Quantified mass of VOCs and volume of gas sample was used to estimate gas concentration.

VOCs were collected via (4 mm O.D., 0.10 m long) sorbent tubes constructed of 304-grade stainless steel that had been double passivated with a proprietary surface-coating process. Tubes were packed with 65 mg Tenax TA sorbent. Silanized glass wool plugs and stainless steel screens were placed in the two ends of the tubes to hold the sorbent. Before the first use, sorbent tubes were conditioned by thermal desorption (260 °C for 5 h) under a 100 mL/min flow of He. For subsequent uses, pre-conditioning at 260 °C for 30 min was tested as sufficient and applied for all tubes. Field air samples were taken using a portable sampling pump with a set flow rate of 50 mL/min for 15 min, and analysis within two days. The sampling flow rates were checked with a NIST-traceable digital flow meter (Bios International, Butler, NJ, USA) (Figure 9).

Chemical analyses of swine odorants were completed using the TD-MDGC-MS/O system (Figure 8). The TD system consists of a Model 3200 automated thermal desorption inlet for Agilent 6890 GC developed by Microanalytics (Round Rock, TX, USA) based on a PAL® autosampler. The unique design of the Model 3200 system allows for gentle purging of air and water from sorbent tubes prior to a single-step sample desorption and introduction to GC. This system eliminates desorption followed by a separate step of cryotrapping and subsequent rapid desorption. Instead, samples are desorbed directly onto the front of GC column, then directly swept column, eliminating problems associated with a typical desorption-trapping-desorption and problems with the presence of water/air in sorbent tubes.

Multidimensional GC-MS/O (Microanalytics) was equipped with two columns connected in series. The non-polar pre-column was 12 m, 0.53mm i.d.; film thickness, 1_μm with 5% phenyl methylpolysiloxane stationary phase (SGE BP5) and operated with constant pressure

mode at 8.5 psi (0.58 atm). The polar analytical column was a 25m×0.53mm fused silica capillary column coated with poly (ethylene glycol) (WAX; SGE BP20) at a film thickness of 1_μm. The column pressure was constant at 5.8 psi (0.39 atm). System automation and data acquisition software were MultiTrax™ V. 6.00 and AromaTrax™ V. 7.02 (Microanalytics) and ChemStation™ (Agilent, Santa Clara, CA, USA). The general GC run parameters used were as follows: injector, 260 °C; FID, 280 °C, column, 40 °C initial, 3 min hold, 7 °C/min, 220 °C final, 10 min hold; carrier gas, GC-grade helium. The GC was operated in a constant pressure mode where the mid-point pressure, i.e., pressure between pre-column and column, was always at 5.8 psi (0.39 atm) and the heart-cut sweep pressure was 5.0 psi. The MS scan range was 33 to 280 m/z. Spectra were collected at 6 scans/s using scan and selective ion monitoring (SIM) simultaneously. Mass calculations were based on SIM scans. Electron multiplier voltage was set to 1000 V. MS tuning was performed using the default autotune setting using perfluorotributylamine (PFTBA) daily. (Cai, 2010)



Figure 15. Pilot scale sampling setup for VOCs collection via sorbent tubes. Sampling pump pulls gas sample from the reactor vent line through the sorbent tube (4 mm O.D., 0.10 m long,

packed with Tenax TA) and the gas flow rate is monitored via inline flow meter for the predetermined sampling time. Total gas sample volume can be estimated as a product of measured flow rate and sampling time.

AMMONIA AND HYDROGEN SULFIDE



Figure 16. Drager portable gas analyzer used to measure NH_3 and H_2S from the vent line of the manure storage reactor via the gas sampling station.

Ammonia and H_2S concentrations were measured via a Drager X-am 5600 portable gas analyzer (Figure 10) with NH_3 and low range H_2S XS sensors. Analyzer was calibrated using Drager calibration software, Environics 4040 gas dilution system (Tolland, CT, USA) and standard gases (Praxair, Ames, IA, USA) (NH_3 : 298 ppm and H_2S : 50.4 ppm).

Ammonia measurement needed compensation for H_2S to avoid false readings. The Drager 5600 analyzer manual briefly mentions that the H_2S may interfere with NH_3 measurement. Thus, the following compensation was developed to account for H_2S interference on NH_3 concentration (Eq. 1). Compensation determination was accomplished with standard gases.

$$C_a = C_m - (C_{H_2S_m}S + b)$$

Eq. 1

Where:

C_a is the corrected NH_3 concentration in ppm,

C_m is the measured NH_3 concentration in ppm,

$C_{H_2S_m}$ is the measured H_2S concentration in ppm,

S and b are the best fit coefficients with S being the slope and b being the y intercept of the standard curve of the NH_3 response to H_2S .

The NH_3 response to H_2S (Figure 11) was determined by reading standard concentration of H_2S with the Drager analyzer and observing the NH_3 response over the H_2S concentration range of 0 to 50.4 ppm. This was done in duplicate to determine the correction needed for accurate NH_3 measurements in the presence of H_2S (i.e., a typical situation in livestock housing with manure storage).

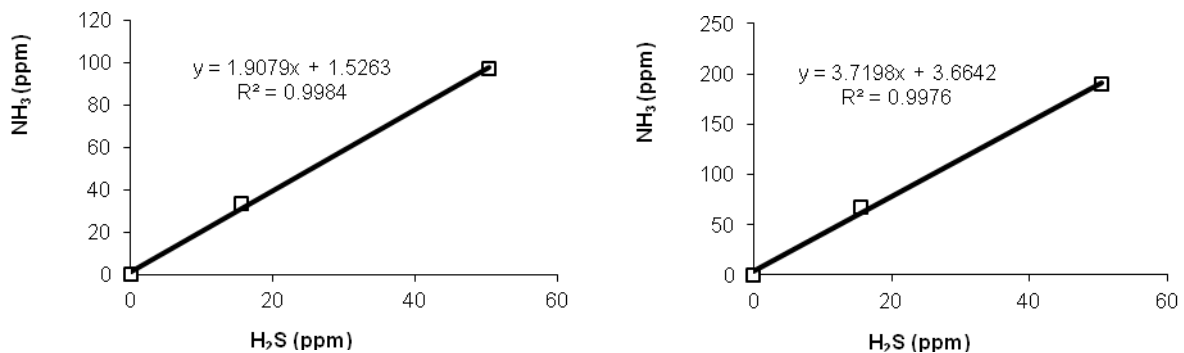


Figure 17. Standard curve used to adjust the Drager analyzer response to NH_3 in the presence of H_2S (0-50.4 ppm) for each Drager analyzer.

SWINE MANURE ANALYSIS

Swine manure analysis was completed using the following standard methods:

- TKN – Standard Method 2001-11 (AOAC, 2000) –Kjeldahl digestion in block digester with Fisher digestion tablets as a catalyst followed by steam distillation and titrimetric analysis.
- Ammonia (NH₃) – Standard Method 4500-NH₄ B & C- Preliminary steam distillation followed by titrimetric analysis (APHA, 1998).
- Dissolved reactive phosphorus – Standard Method 4500-P E (APHA, 1998) – Filtration to 0.45 μm to remove particulates followed by the ascorbic acid method.
- Total phosphorus – Standard Method 4500-P B.4 & E (APHA, 1998) Sulfuric acid-nitric acid digestion in a block digester followed by the ascorbic acid method.
- pH –Standard method 4500-H+B. Electrode method (APHA, 1998).
- Total solids/moisture content and volatile solids – Standard Method 2540 G (APHA, 1998) – dried for 24 hours at 105°C for 24 hours (constant weight) for total solids followed by ignition at 550°C for 1 hour for volatile solids.

ESTIMATION OF GAS FLUX (EMISSIONS FROM MANURE IN MASS/TIME/AREA)

Measured gas concentrations were used for estimation of flux, i.e., emissions from manure based on time and surface area of manure. Gas concentrations were measured at field conditions and required conversions to standard conditions.

Conversion to gas concentration in mass per volume from measured ppm for NH₃, H₂S, CH₄, CO₂ and N₂O in μg/mL is shown in Eq. 3.

$$C = \frac{C_a * P}{R * T * 1000} \text{ molwt}$$

Eq. 3

Where:

C is the gas concentration in $\mu\text{g/mL}$.

C_a is the measured (for NH_3 it is the adjusted) concentration in ppm.

P is the atmospheric pressure in atmospheres.

R is the ideal gas constant, $0.082057 \text{ L atm K}^{-1} \text{ mol}^{-1}$.

T is the measured temperature in Kelvin.

molwt is the molecular weight of the gas.

Eq. 4 was used to convert C (mass/volume) to EPA standard conditions (1 atm, 25 °C, dry air) with humidity adjustment to dry air:

$$C_{std} = \frac{C}{\left(\frac{P_m}{760}\right)\left(\frac{298}{T_m}\right)\left(\frac{1}{1-H}\right)} \quad \text{Eq. 4}$$

Where:

C_{std} is standardized and humidity factored in gas concentration in $\mu\text{g/mL}$.

C is the concentration in $\mu\text{g/ml}$ from Eq. 3.

P_m is the measured atmospheric pressure in mmHg.

T_m is the measured temperature in Kelvin.

H is the humidity ratio determined by measured relative humidity and the use of a psychrometric calculator to adjust to standardized air.

Ventilation rate of the pilot scale storage simulators using the inline rotameters is shown in Eq. 5.

$$Q_{air} = \frac{R_m * S + b}{\sqrt{\frac{P * 14.7}{530 * T}}}$$

Eq. 5

Where:

Q_{air} is the ventilation rate in ml/min.

R_m is the measured reading from the rotameter.

S is the slope from the factory rotameter calibration data (111.81).

b is the y intercept from the factory rotameter calibration data (127.11).

P is the measured pressure in psi.

T is the measured temperature in Rankine.

Q_{air} was then adjusted to EPA standard conditions with humidity adjustment to dry air as C_{std} using Eq. 6

$$Q_{air_{std}} = Q_{air} \left(\frac{P_m}{760} \right) \left(\frac{298}{T_m} \right) \left(\frac{1}{1-H} \right)$$

Eq. 6

Where:

P_m is the measured atmospheric pressure in mmHg.

T_m is the temperature in Kelvin.

H is the Humidity Ratio determined by measured relative humidity and the use of a psychrometric calculator.

Emissions may then be calculated with Eq. 7:

$$E = \frac{Q_{air_{std}} * C_{std} * 60}{1000}$$

Eq. 7

Where:

E is emissions in mg/h.

$Q_{air_{std}}$ is from Eq. 6.

C_{std} is from Eq. 4.

The flux (emissions) were then related to the manure surface area Eq. 8.

$$E_{surface} = \frac{E}{A}$$

Eq. 8

Where:

$E_{surface}$ is in mg/h/m².

E is from Eq. 7.

A is the surface area of manure in square meters.

Concentrations of VOCs were estimated based on gas sampling with sorbent tubes. Mass of VOCs trapped on sorbent tubes was estimated using GC-MS. Volume of air sample pumped through a sorbent tube was based on the measured air flow rate and sampling time (Eq. 9):

$$V_s = F * t$$

Eq. 9

Where:

V_s is the volume of air that was sampled through the tube in mL.

F is the average of the measured flow rate through the tube in mL/min.

t is the time in min in which the sampling was taken.

The sample volume was then adjusted to standard conditions with Eq. 10.

$$V_{s_{std}} = V_s \left(\frac{P_m}{760} \right) \left(\frac{298}{T_m} \right) \left(\frac{1}{1-H} \right)$$

Eq. 10

Where:

$V_{s_{std}}$ is the standardized volume of air that was sampled through the tube in mL.

V_s is from Eq. 9.

P_m is the measured atmospheric pressure in mmHg.

T_m is the temperature in Kelvin.

H is the Humidity Ratio determined by measured relative humidity and the use of a psychrometric calculator.

The concentration of the VOC were calculated with the volume of air sampled and the mass that was determined by GC-MS and the determined MS detector response factor in Eq. 11.

$$C_{std} = \frac{m}{V_{s_{std}}}$$

Eq. 11

Where:

C_{std} is the standardized concentration of VOC in ng/mL.

m is the mass determine by GC-MS in ng.

$V_{s\ std}$ is from Eq. 10.

Emissions then were calculated in Eq. 12.

$$E = Q_{air\ std} * C_{std} * 60$$

Eq. 12

Where:

E is emissions in ng/h.

$Q_{air\ std}$ is from Eq. 6.

C_{std} is from Eq. 11.

The VOC emissions (flex) were then related to the manure surface area Eq. 13.

$$E_{surface} = \frac{E}{A}$$

Eq. 13

Where:

$E_{surface}$ is in ng/h/m².

E is from Eq. 12.

A is the surface area of manure in square meters.

RESULTS/DISCUSSION

Manure emissions were collected and analyzed over the course of the experiment. The following results were obtained for average and cumulative emissions, which are displayed in the table below.

Table 5. Analysis of manure emissions for different manure types and treatments.

Item (mg/h/m ²)	Treatment					Standard Error	Significance		
	Crusted Control	Crusted Treatment	Crusted Double Treatment	Uncrusted Control	Uncrusted Treatment		Manure Type	Treat- ment	Inter- action
NH₃ Emissions (Average)	145	135	125	176	175	4.78	<0.0001	0.2886	0.4183
NH₃ Emissions (Cumulative)	1.70x10 ⁴	1.58 x10 ⁴	1.46 x10 ⁴	2.06 x10 ⁴	2.05 x10 ⁴	598	<0.0001	0.3113	0.3952
H₂S Emissions (Average)	0.575	0.598	0.285	3.14	1.64	0.404	<0.0001	0.1386	0.1278
H₂S Emissions (Cumulative)	67.2	70.0	33.4	367	192	53.6	0.0028	0.1386	0.1278
CH₄ Emissions (Average)	144	153	131	22.8	20.8	6.93	<0.0001	0.6286	0.4468
CH₄ Emissions (Cumulative)	1.68 x10 ⁴	1.79 x10 ⁴	1.52 x10 ⁴	2.27 x10 ³	2.43 x10 ³	833	<0.0001	0.6286	0.4468
CO₂ Emissions (Average)	8.70 x10 ³	8.86 x10 ³	8.78 x10 ³	8.52 x10 ³	1.04 x10 ⁴	717	0.3805	0.1926	0.2646
CO₂ Emissions (Cumulative)	1.01x10 ⁶	1.03 x10 ⁶	1.02 x10 ⁶	9.94 x10 ⁵	1.21 x10 ⁶	8.43 x10 ⁴	0.3848	0.1944	0.2824

The analysis of manure emissions showed no significant difference for the treatment effect or manure * treatment interaction for any of the emissions measured. Although the difference was not significant, treatment differences were noted as ammonia emissions were lower for treated manure compared to untreated manure for both manure types, showing that there was a downward trend in ammonia emissions as dosing rate increased. For this reason, treating manure with a higher dose of More than Manure could result in differences. Trends between treatments for other emission types were not observed in this study. Manure types had significantly different emissions for ammonia, hydrogen sulfide and methane between crusted and uncrusted manures. This could be a result of different properties between manure types, which are listed in table 6 below.

Table 6. Analysis of manure characteristics for different manure types and treatments with statistical analysis.

Item	Treatment Results					Standard Error	Significance		
	Crusted Control	Crusted Treatment	Crusted Double Treatment	Uncrusted Control	Uncrusted Treatment		Manure Type	Treatment	Inter-action
NH₃ (mg/L)	40.6	39.3	37.8	20.1	19.2	1.41	<0.0001	0.4549	0.9121
PO₄ (mg/L)	179	172	165	86.5	69.9	6.20	<0.0001	0.4556	0.1801
Total Solids (%)	5.31	5.08	5.04	2.27	2.43	0.189	<0.0001	0.8677	0.319
Volatile Solids (%)	3.70	3.63	3.45	1.33	1.36	0.180	<0.0001	0.9195	0.8852
Volatility (%)	68.5	69.8	66.6	57.2	55.4	0.164	<0.0001	0.8775	0.5217
COD (mg/L)	5010	5220	5070	2890	2910	213	<0.0001	0.6091	0.7961
pH	8.21	8.20	8.21	8.12	8.17	0.0349	0.1242	0.5047	0.4253

Testing two manure types helped diagnose the sorption mechanism of the acidic copolymer additive to determine if CO₂ released during acidification will create a more uniform crust and thus retain more emissions in the manure. For example, the crusted manure had higher COD, which could have resulted in higher CH₄ emissions. This is because COD represents the amount of carbon in the manure and the more carbon available, the higher the potential for anaerobic bacteria to use this material to produce methane during methanogenesis. This was shown in a study by Gungor-Demirci and Demirer (2004) where they found that anaerobically digested cattle and broiler manures with higher COD had higher biogas production.

Additionally, the crusted manure had significantly higher ammonia in the manure than the uncrusted manure, however the emissions of ammonia from the crusted manure were significantly lower. This could indicate that the crust on the manure played a role in emissions. This is because manure surface crusts typically contain a layer of organic matter, which can affect nitrogen transformations and losses, because the crust can provide a barrier against gas exchange from the manure (Petersen and Sommer, 2011). This effect was noted by Sommer et al. (2000) and VanderZaag et al. (2008) whom found that manures with natural crusts had lower ammonia emissions than uncrusted manures. The diet of the animals might also play a role in emissions because the amount of protein fed to the animals can affect the amount of nitrogen in the manure. Portejoie et al. (2004) found that ammonia emissions were decreased by 63% when the protein in the diet was decreased from 20% to 12%.

CONCLUSIONS

Based on the results, it is possible that More than Manure has the potential to reduce ammonia emissions, however future work might consider using a higher dosing rate to achieve greater emissions.

At this time it does not appear that More than Manure would be a cost effective method to reduce emissions. Based on the differences in emissions observed between different manure types, it would be beneficial to develop a better understanding of the mechanisms within the manure that caused the decrease and better ways to utilize mechanism to improve efficacy of product. Since manure characteristics can be variable from farm to farm, it could be possible that More than Manure could work in certain situations where manure characteristics are different than those tested in this experiment.

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CHAPTER VI

SUMMARY CONCLUSIONS

SUMMARY

In summary, there were two main points that this thesis explored: the benefit of placing a value on scientific recommendations through the concept of value of information and a potential best management practices that could be effective at reducing ammonia emissions.

Chapters II and III explain that environmental concerns and economics can align, but scientists should do a better job of helping farmers and non agricultural entities understand the situation and why management practices are important.

Chapters IV and V explain that reducing ammonia emissions is important, but the strategy of treating manure with More than Manure was not effective.

CONCLUSIONS

In conclusion, as agriculture continues to expand, improving and develop best management practices for manure to reduce negative impacts on the environment and increase profit for the farmer. All aspects of sustainability including social, environmental and economical components should be considered and this can be achieved by promoting interdisciplinary work between scientists as well as improving ways to communicate research to farmers in a way that is understandable and practical to their operations. Therefore, additional research should be done to address this issue. A better approach could be to look at addressing manure management concerns by using a whole systems approach which would look at improving various aspects of animal productions to treat the externalities rather than

using one treatment. These two aspects of agriculture could help reduce unwanted losses and improve efficiency in order to make agriculture more sustainable.