Title: A Meta-analysis of best practices for management and land application of swine manure in the Midwestern United States – **NPB #13-046**

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Industry Summary:

Many conservation practices are currently used within the swine production industry, but not universally adapted. The goal of this project was to identify currently available and technologically feasible on-farm best management practices and technologies for storage and land application of swine manures and to quantify their performance in terms of reduced impacts on water quality and economic feasibility when implemented on Midwestern US swine operations. This was done by performing a literature review of scientific databases on techniques of manure land application and storage practices. Increased information about the impact of these practices and the economic impact they may have on farming operations is important parts of the puzzle in improving farm sustainability and decreasing potential impacts on water quality.

One of the largest manure questions is how much is there and is this too much for a local region to use. Essentially, this question is asking how does the amount of manure nutrients produced within an area compare to the crop's capacity to utilize these nutrients. This was evaluated from Iowa by using Census of agriculture data to determine animal and crop production amounts, which were used to estimate manure production and crop nutrient removal. The results of this analysis indicated that the manure produced annually in Iowa was capable of supplying about 30% of the nitrogen and phosphorus removed with harvested crop material. The analysis was repeated at the county level, with the results indicating that 92 of the 97 counties in Iowa obtained less than 70% of their nitrogen and phosphorus needs for crop production from manures. These results indicate that in general, there is sufficient land to appropriately utilize the manure produced.

Utilizing manure nutrients to support crop production is one of the most common methods of treating swine manure. Doing so requires information about the manure's nutrient composition be obtained so that appropriate management decisions about how much manure should be applied to support crop production. This makes manure nutrient testing an important component of any farm nutrient management plan. However, previous survey have indicated only about 20-30% of farms annually sample their manure for nutrient analysis, with one of the potential reasons for this being a perceived lack profitability associated with manure sampling. To evaluate this we developed an economic model to determine what the impact of knowing manure nutrient composition would have on farm management decisions and how this would impact economic returns. The

results indicated that whether applying manure at a nitrogen or phosphorus limited rate sampling and testing the manure always resulted in increased economic returns. The results indicated that if applying at a nitrogen limited rate, sampling before manure application was recommended and if applying at a phosphorus limited rate, sampling at the time of manure application was recommended.

Another technology that is often discussed with manure is nutrient separation techniques, often called solid separation. The idea behind this approach is to create a nutrient dense, solids rich product that could be transported greater distances from the farm while applying keeping the nutrient depleted, water rich fraction near the farm. The idea is that this would reduce the cost of land application of manure. Though numerous technologies to achieve this have been proposed and evaluated, there has not been an effort to evaluate what farm characteristics as well as separation performance would be required to make these technologies cost effective. Thus, we developed an economic model that would relate application costs to the effectiveness of nutrient partitioning, farm size, and crop production characteristics. The results indicated that for typical farms in the Midwestern United States existing technologies of nutrient partitioning were generally not cost feasible; however, for large farms with situation were manures need to be transported longer distances the technology may be applicable.

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Scientific Abstract:

Manure utilization and the impact of animal production on the environment is a topic of increasing importance as greater emphasis is placed on sustainability and environmental quality. A large quantity of data exists on manure's use as a fertilizer to support crop production as well as its potential impacts on environmental quality; however, often times these works aren't placed in a larger overall context that facilitates decision making on the part of the farmer based on the results. Thus, this work focused on researching these practices in a manner that also focused not only on the manure and the environment, but also the economic realities of different decisions.

Our first objective was to provide a method of determining whether manure was being seen as a waste that needed to be disposed or a resource that could be used to support crop production. This was done by performing a county-by-county estimate of manure nutrient excretion and its nutrient content from all animals produced within a county and comparing it to the estimated crop nutrient removal of nitrogen and phosphorus. This analysis was conducted for Iowa and all Census of Agriculture surveys since 1970. A statewide analysis of crop and animal production in Iowa suggests that about 30% of current nitrogen and phosphorus requirements for crop production could be supplied from manures and litters, while around 40% of the required potassium could be provided. However, neither livestock nor crop production is uniformly distributed across all counties. This unequal distribution suggests that a more disaggregated analysis of crop nutrient requirements and manure nutrient supply is necessary to estimate the risks of excess nutrient loss to the environment. Results indicated that in general all counties had sufficient nutrient utilization capacities to value manure as a resource; however, counties in Northwest Iowa are becoming progressively more manure rich, while counties in Southwestern and Central Iowa are becoming progressively more manure poor. This separation of crop and livestock production is becoming more pronounced, indicating that solids separation and nutrient (especially phosphorus) recovery systems that can concentrate manure nutrients for transport could become more important to help counties maintain nutrient balance and to return manure nutrients to the soil if these trends persist.

Our second and third objectives focused on evaluating two potential practices animal farms could use in handling their manure. The first is manure sampling and testing. It is recognized that manure sampling can reduce environmental impacts as it facilitates selection of proper manure application rates, but little data on its

economic impact exist. Similarly, nutrient separation techniques are often proposed to create nutrient rich and nutrient poor manure products. The nutrient rich manure could then be more economically transported further from the farm, reducing manure application costs. Though various techniques have been evaluated, no effort has been made to determine what cost and performance requirements are needed to make these technologies economically feasible. To facilitate analysis of these cases economic models were developed. We used value of information theory to determine how information on manure nutrient content could be used to improve selection of manure application rates and the potential benefit this could have in cost savings due to reduced purchase of commercial fertilizer or improved crop performance, depending on if the estimated nutrient concentration would have resulted in under- or over-application of manure nutrients. Similarly, an economic model was used to evaluate how different nutrient partitioning performances would impact manure application costs of farms of various sizes and production characteristics to determine what a farm could pay for a nutrient separation technology

Introduction:

Driven by world-wide population increases, growing incomes, and increased urbanization, society has experienced a marked and rapid dietary transformation (Smil, 2002). Specifically, there has been an increase in per capita demand for animal proteins (meat, milk, and eggs). Future forecasts of global meat demands generally expect an increase of 50% over the next two generations (due mostly to changes in developing countries). In an effort to meet societal demands of food and fiber agriculture has experienced numerous changes over the years. One of these being the use of mineral fertilizers, which allowed decoupling of crop and animal production systems, as for the first time crop production was no longer limited to the use of animal wastes, green manures, and natural soil fertility to support crop production. In many cases, this change led to increased farm sizes (more acres per farm or animals per farm), an operational separation of crop and livestock production as farms became more specialized (Naylor et al., 2005), and an increased use of animal confinement facilities as pasture systems gave way to confinement facilities and row-crops production as the growth of higher-value crop commodities could be supported by the readily available mineral fertilizers.

Society fears that the trend of increasing demand for meat and livestock products and the associated growth of the animal production industry will result in greater amounts of manure, in many cases beyond the ability of the soil around the facility to utilize it (Karlen et al., 2004). Additionally, it has been suggested that intensification and industrialization of agriculture, specifically animal agriculture, has resulted in concentration of waste products associated with their production (manures, wash-down water, process waters, etc.) over relatively small geographic regions that are spatially segregated from crop production areas. Since the distance that manure can be economically hauled for land application has practical limits, the public fears that this spatial separation between crop and animal production areas could lead to over-application of manure nutrients, i.e., in excess of crop nutrient demand, near animal production facilities, and thus potentially increase transport of nutrients to ground and surface waters.

Moreover, it has been recognized for years that manures are a valuable soil amendment due to their potential contribution to improved soil quality. As stated by Drinkwater et al. (1998), as compared with senescent-crop residues, a larger proportion of manure-derived carbon is retained in the soil. The return of manure to the soil is thought to improve soil structure, tilth, and water relations (holding capacity, available water content, and conductivity). Additionally, the use of manures as a fertilizer is well accepted as there are numerous macro- and micro-nutrients it provides to support crop growth. More recently it has been suggested that the return of manure to the land can be an important component of sustainable agriculture systems. Specifically, Sulc and Tracy (2007) identified four positive factors associated with livestock being integrated into cropping enterprises, these were: (i) crops can be used to feed livestock minimizing the import of outside feed stuffs, (ii) livestock manure can serve as a source of nutrients for crop production, (iii) livestock can serve as a sink for agricultural by-products, and (iv) ruminant livestock encourage the establishment of perennial grass and legume forages as a feedstuff.

This dichotomy, manure as either a waste or a resource, has long defined the issue of manure management. The debate has only intensified as demand for animal protein and agricultural sustainability has increased. Opinions on how to achieve this improved sustainability vary greatly with some arguing that animal production needs to be minimized or eliminated completely (due to the inherent inefficiency in conversion of plant energy and protein to animal energy and protein), while others argue for the encouragement of animal production as part of organic systems where the manure serves as the main fertilizer source for crop production. Even opinions over the types of animals that should be raised varies, with the argument for poultry and pork based on better feed conversion efficiencies of these species compared to cattle and the argument for cattle based on the fact that as ruminants they can convert grasses and forages into human consumable proteins. These issues illustrate that understanding manure nutrient availability and crop nutrient demands is an important component in evaluating agricultural sustainability. Moreover, comparisons of manure nutrients to crop nutrient demand provides a sense of the "value of the manure," i.e., whether it will be treated as a waste or resource in different regions.

Thus, researchable questions include: 1) How much manure is being produced and how does this compare to crop nutrient need, 2) as most manure is utilized as a fertilize, how does implementation of the management practice of annual manure nutrient sampling and testing impact our manure management and specifically does it provide and economic benefit, and 3) as nutrient separation techniques are often proposed as a management practice to improve manure use as a fertilizer, what performance and cost characteristic are required to make it economically feasible on farms in the Midwestern United States.

Objectives:

1. Evaluate the amount of manure produced in Iowa and compare this to the state's capacity to use these nutrients for crop production.
2. Evaluate the economic benefit that can be realized from a farm manure sampling and testing program.
3. Evaluate the economic feasibility of nutrient separation systems for use on animal farms in terms of potential cost saving during land application of manures.
4. Evaluate manure application separation distance and evaluate if other best management practices would be capable of achieving similar levels of performance.

Materials & Methods: This section should include experimental design, methods and procedures used, number of animals, etc.

This study as proposed was a meta-analysis. Thus, no designed experiments were performed, instead the existing scientific literature was surveyed to evaluate different manure storage, treatment, and application practices to determine how different practices impacted nutrient loss from animal farms and how different application practices changed nutrient loss.

Originally, the focus was on land application practices; however, results of the literature review indicated that in most cases results were similar to those reported in the Iowa Nutrient Reduction Strategy. For an overview see Iowa Strategy to Reduce Nutrient Loss: Nitrogen Practices and Phosphorus Practices (available at http://www.agronext.iastate.edu/soilfertility/info/SP435.pdf). Given this recent summary, we chose to focus on nutrient management aspect that had not been recently summarized, including economics related to manure management.

As this was not a designed experiment, a different approach as used for each of the specific objectives. Thus, within the results section a discussion of the methodology used for each objective is provided.

Results:

Objective 1. Manure Nutrient Availability Relative to Crop Nutrient Capacity:
How much manure is there?

Summary

    A common question about manure management in Iowa is how much of our land is receiving manure. This question is often asked after hearing statistics like animal farms in Iowa produce nearly 10 billion gallons of manure per year, or the pollution potential of animal manure in Iowa is the equivalent to that of 45 million people; 15 times the state's current population. Comments like these often lead to thoughts of manure piling up, farmers doing everything they can to get rid of manure, and insufficient land on which to apply the manure. However, what is the truth behind these numbers and what does the manure situation in Iowa really look like? Over the next few paragraphs, we will take a closer look at these issues.

    Data from the 2012 census of agriculture was used to estimate livestock populations and production within each county. Available nutrients in manure were calculated by estimating average animal populations and multiplying this value by a manure production coefficient, a manure capture coefficient, the amount of nutrient expected to remain in the manure after storage, and finally the percent of those nutrients that would be crop available. These calculations were performed for both nitrogen and phosphorus.

    The nutrient assimilative capacity of cropland was estimated by multiplying the amount a crop produced in 2011 times the nutrient content of that crop. This is a low estimate of actual crop need as it only considers nutrients exported with the grain. Additionally, nitrogen requirements for production of soybean or alfalfa were not included. These plants are both legumes, meaning that can obtain some of their nitrogen from the air; however, research has shown that these plants tend to use nitrogen available in the soil first and in some cases may require supplemental nitrogen to achieve desired yields.
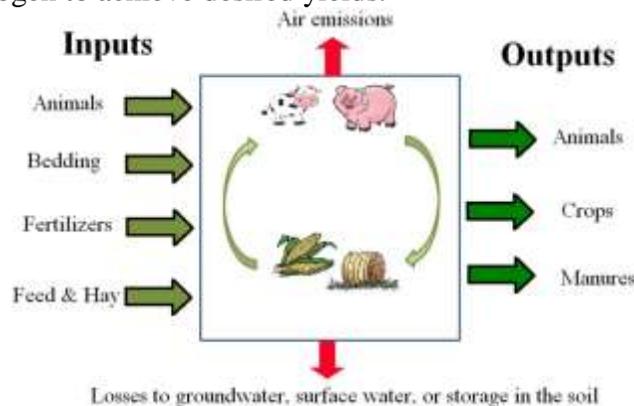
Figure 1. Schematic of nutrient budget.

    As you may be aware, there is considerable livestock production in Iowa as it currently leads the nation in both swine and egg production, is in the top ten in beef and turkey production, and twelfth in dairy production. All these animals result in the production of over 50 million tons of manure, 325,000 tons of available nitrogen, and 82,000 tons of phosphorus annually. Although this may sound like a lot, it took almost 1 billion tons of nitrogen and 220,000 tons of phosphorus to support the growth of corn and soybeans in Iowa in 2011. This means that only about 30% of our nitrogen and phosphorus needs for crop production could potentially be supplied with animal manures.

    In terms of crop acres receiving manures a few more calculations are required. In Iowa, all confinement farms with over 500 animal units are required to submit a manure management plan to the Iowa Department of Natural Resources. Procedures in this plan specify how to calculate the maximum amount of manure that can be applied to a field. Based on the Iowa DNR requirements, the 325,000 tons of nitrogen from manure would be

enough for about 3.8 million acres of corn per year. In 2012, there were 13.7 million acres of corn harvested in Iowa and another 9.3 million acres of soybean. This means only about 17% of Iowa's farmable acres received manure in any given year.

These figures indicate there is sufficient land in Iowa to utilize all our animal manure, but as animal production is not uniformly distributed across the state, a closer look at county level nutrient balances is also of interest. This was done by comparing the estimated amount of available manure nitrogen and phosphorus to the crop nutrient assimilative capacity within that county.

In figure 2 and 3, counties that are various shades of green receive less than half their nitrogen or phosphorus needs from manure. As counties become progressively more yellow and then red they are capable of getting more of their nutrient needs from manures. In looking at these results, it is clear that the majority of counties have sufficient need for the nitrogen and phosphorus in the manure to make it a valuable resource in those counties.
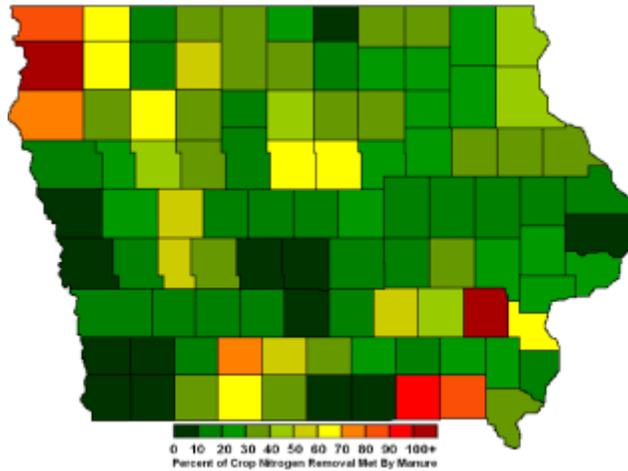

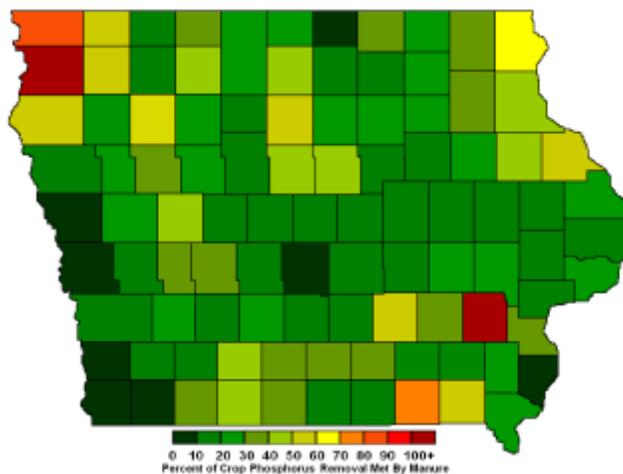**Figure 2. Available manure nitrogen as a percent of nitrogen removed with crop harvest.**

Figure 3. Available manure phosphorus as a percent of phosphorus removed with crop harvest.

Although, these results provide insight into the current manure situation within a county, it should be recognized that they are sensitive to the assumptions made about both manure production and crop nutrient needs. Of particular concern, crop production in 2011 was somewhat suppressed, in south and southeastern Iowa, due to drought conditions. For this reason, we are also presenting the results in a second way. Figures 4 shows the pounds of manure nitrogen per acre of corn; figure 5 shows the pounds of phosphorus per acre of cropland in the county. For comparative purposes, fertilizer requirements would be about 150-200 pounds N per acre corn and about 27 pounds of phosphorus per acre cropland, meaning most counties could utilize all their manure.
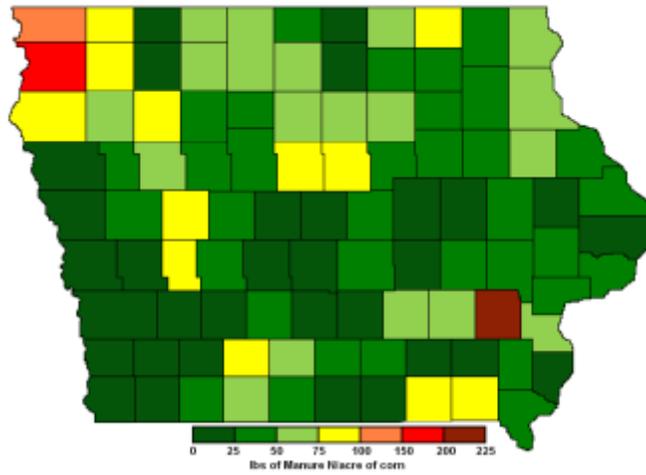
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Figure 4. Available manure nitrogen per acre of corn within the county.
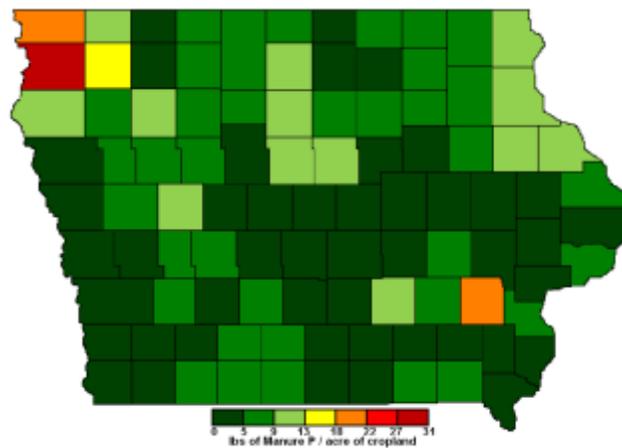

Figure 5. Available manure phosphorus per acre of cropland within the county.

A County-Level Assessment of Manure Nutrient Availability Relative to Crop Nutrient Capacity in Iowa: Analysis of Spatial and Temporal Trends

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intensification and industrialization of agriculture, specifically animal agriculture, has resulted in concentration of waste products associated with their production (manures, wash-down water, process waters, etc.) over relatively small geographic regions that are spatially segregated from crop production areas. Since the distance that manure can be economically hauled for land application has practical limits, the public fears that this spatial separation between crop and animal production areas could lead to over-application of manure nutrients, i.e., in excess of crop nutrient demand, near animal production facilities, and thus potentially increase transport of nutrients to ground and surface waters.

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Specifically, the intensification of animal agriculture has led many to question whether different agricultural areas have sufficient land to utilize the manure being produced (Smil, 2002), such as Iowa. An aggregated analysis (statewide) of crop and animal production in Iowa suggests that about 25% of the nitrogen and phosphorus requirements, and 40% of the potassium, for crop production could be supplied from manures and litters generated from livestock production. However, a more interesting question is how this varies spatially throughout the state, i.e., are there areas where manure nutrient production is greater than crop demand, and how has this changed temporally. Thus, our objective is to explore if animal production in Iowa is intensifying to such a degree that in certain areas of the state manure will not be viewed as a resource, but instead a waste that the animal production facility must find a way of disposing of, and to examine if/how this has changed over time, i.e., are these issues becoming more frequent. I hope that this work can be utilized to evaluate where manure treatment strategies that partition and remove nutrients may be most practical, or even necessary, to implement (areas where the manure nutrients cannot be utilized) and also to identify locations where more manures could be desired (to reduce the reliance on synthetic fertilizers). Specifically, I (1) quantify the extent to which livestock production has become more spatially concentrated by determining the production of animal manure and manure nutrients on a statewide and county basis, (2) quantify the extent to which the production of manure nutrients may exceed the capacity of crop land to assimilate the nutrients, (3) identify counties that are more likely to have animal waste utilization problems and be in need of innovative manure treatments, and (4) to quantify how these issues have evolved over time. Future work on these issues could evaluate how changes

in animal production strategies (pasture versus containment based facilities) and crop rotation choices (continuous corn, corn-soybean, small grains, or increased alfalfa hay) impact these nutrient balances and the extent to which manure is being viewed as a resource or waste.

Materials and Methods:

Data from the census of agriculture were used to make estimates of crop and livestock populations and production. The census of agricultural producers is conducted periodically (approximately every 5 years) by the USDA National Agricultural Statistics Service (NASS). Electronically published censuses (www.agcensus.usda.gov/Publications/index.php) were utilized for data collection; censuses from 2007, 2002, 1997, 1992, 1987, 1982, 1978, 1974, 1969, 1964, 1959, 1954, 1950, 1945, 1940, 1935, 1930, and 1925 were utilized. Classifications of animals and crops have varied slightly over the years; the distinctions and how these changes were handled will be discussed individually for each animal type and where applicable crop production type. In the following sections the method of estimating crop nutrient assimilative capacity of the crop land will first be described, followed by estimation of animal manure production and nutrient content. In addition to these data, crop production data was also supplemented using data from the Iowa Agricultural Statistics which is produced annually.

Estimating the nutrient assimilative capacity of crop land

The assimilative capacity is an estimate of the amount of nutrients that could be applied to land available for manure application without building up nutrient levels in the soil over time, i.e., at agronomic rates. Specifically, our definition will only include an estimate of the amount of nutrient contained in the harvested portion of the removed biomass, and as such is a low estimate of the actual nutrient application that would be required to support these production levels as some nutrient would inevitably be lost to erosion, surface runoff, leaching, gaseous emissions, fixation by the soil, and possibly harvest of additional portions of the crop residue. The extent to which nutrients are lost to each of these mechanisms is dependent on the specific nutrient, the conditions of the field and soil, the weather conditions of a particular year, the method, timing, and rate of nutrient application, as well as the timing of field tillage, planting, and harvesting practices, and all their interactions. The calculated estimate of assimilative capacity includes all farms within the, not just those with livestock, and thus assumes that these operations would be willing use manure as a fertility source.

It should be recognized that this estimate of assimilative capacity is for actual assimilative capacity during the particular year of the census. This is impacted by both the crop choice during the given year and the growing conditions specific to that year and in many cases may be below the assimilative capacity estimated by the producer determining appropriate nutrient application rates. In general this isn't an issue of concern as most census years were representative of crop production in the year immediately preceding and following the census year; however, crop yields in 2012 were reduced as compared to other recent years due to drought conditions prevalent throughout much of the state and thus provide a low estimate of the potential nutrient utilization capacity the producer would have estimated.

Estimates of the kilograms of nitrogen, phosphorus, and potassium per unit of crop yield were obtained from the USDA NRCS nutrient content of crops database (available at http://plants.usda.gov/npk/main). These estimates were multiplied by the production (either in bushels or metric tons) for each of the crops (corn grain, corn silage, soybeans, alfalfa hay, other hay, oats, wheat, barley, and rye). In this analysis, I assumed that the nitrogen removed with soybeans and alfalfa hay was obtained entirely by nitrogen fixation, i.e., no manure, soil, or synthetic nitrogen was utilized by these crops. This again is a conservative estimate as research has generally supported that if mineral nitrogen is present in the soil the plant will utilize this to support their growth and development. Moreover, the harvest of crop biomass (wheat, oat, barley, and rye straw, corn stover, and soybean residue) was not considered a part of the nutrient assimilative capacity. This assumption was made as on a statewide basis these residues typically aren't harvested in significant quantities; however, these residues could be harvested for use as bedding materials at some animal operations. In these cases the residues would then be returned with the manure application. More recent use of corn stover to support bioethanol production could alter this production practice and make accounting for nutrients removed with stover harvest necessary.

Table 1. Nitrogen, phosphorus, and potassium contents of the harvested portion of corn, oats, soybean, wheat, barley, rye, alfalfa, corn silage, and grass/clover hay.

Crop	kg N/bushel	kg P/bushel	kg K/bushel
Corn-Field, for grain	0.36	0.07	0.08
Oat, for grain	0.27	0.05	0.06
Soybean, for grain	1.61	0.16	0.38
Wheat-Durum, for grain	0.58	0.10	0.12
Barley, for grain	0.44	0.07	0.09
Rye, for grain	0.48	0.08	0.12
	kg N/metric ton	kg P/metric ton	kg K/metric ton
Alfalfa, for hay	25.2	2.36	19.1
Corn-Field, for silage (dough stage)	3.56	0.53	3.00
Grass and Red Clover, for hay	20.1	2.03	12.6

Estimating Animal Production

Data from the census of agriculture was used to make estimates of livestock populations in each county. Unfortunately, the census of agriculture does not report the average number of animals on a farm during the year, which is needed to estimate manure nutrient production. However, the census typically reports inventory (population currently on hand) and sales data (sold at some point during the year) on the number of head of beef, dairy, swine, and poultry for the census year. These values were used to estimate livestock and poultry populations within the calendar year, which was the basis for estimating total manure production.

Hog and pig production information was obtained from three categories from the census of agriculture. These were an end-of-year inventory of hogs and pigs used for breeding, an end-of-year inventory of other hogs and pigs, and the number of hogs and pigs sold in the calendar year. Using these numbers I calculated the number of pig fattening places as the sum of number of pigs sold plus the end-of-year inventory of other pigs. This sum was divided by three to estimate finishing spaces (this assumes 2.2 to 2.5 turns per year, i.e., that using these number each pig space would be counted three times, once from each turn). A ratio of 20 sows to 1 boar was used to partition the breeding stock into categories of boars and sows. In this analysis I assumed a sow gestation period of 114 days and a farrowing/weaning period of 35 days (76.5% of time in gestation and 24.5% of time farrowing/weaning) to estimate manure production. Prior to 1969 breeding stock inventory wasn't provided. I assumed that breeding stock accounted for 14.7% of total inventory prior to this based on the ratio of breeding stock to total stock in the 1974 census. This ratio was used for every individual county as I anticipated that as I move further back in history there was less pig transfer from county-to-county, i.e., that before this year most swine operations were farrow-to-finish as compared to the specialized farm typical of the modern swine industry. Prior to 1964 only the number of pigs sold was provided. The current fattening inventory was estimated to be about 54.7% (based on the 1969 census) of that sold with breeding stock still 14.7% of total live inventory. Again these estimates were utilized for each county.

End of year beef and dairy cow numbers were provided in the census of agriculture. I assumed that this value represented the average population of dairy and beef cows within each county for that particular year. In many cases the number of dairy and beef heifers was also provided; sometimes this value was divided into categories of less than one year and over a year of age; however, this wasn't always this case. When this data wasn't broken down by age I assumed that ½ of the heifers were less than one year of age and the others were between one and two years of age. If the number of replacement calves wasn't provided it was estimated as a fraction of the other cattle category, which includes steers, calves, and bulls. The number of steers was estimated as the number of cattle on feed. The number of bulls was estimated at 5% of the beef cow inventory. After subtracting the number of bulls and steers from the other cattle category, the remainder was assumed to be replacement heifers which were partitioned into beef and dairy replacements based on the percentage of dairy and beef cows within the county during the census year. In estimating the average population of beef steers (finishing spaces) I summed the end-of-year inventory of cattle on feed with the number of cattle on feed sold.

This total was divided by three to determine an average population (this assumes there will be 2.2 grow-outs per year on a farm).

The final animal category considered was poultry. I considered three species of poultry operations, these included turkeys, layers, and broilers. Turkeys were divided into those kept for laying (reproduction) and market turkeys. The population of laying turkeys was reported in the census of agriculture as the year-end-inventory, this was assumed constant for the year. The number of turkeys sold and the current market turkey inventory were reported. These two values were summed and divided by three to determine the number of market turkey spaces in each county. I assumed that half of the market turkeys were hens and that the other half was toms. The year-end-population of laying hens was provided in the census of agriculture. I assumed this value represented the average population for that year, i.e., that sale of laying hens were balanced with replacements. Typically only the sales of broiler chickens were provided and this value was divided by six to determine the average broiler population during the given year, i.e., six turns of broilers would be produced per year.

Estimating Manure Production and Manure Nutrient Content

The quantity of manure was estimated on both an *as excreted* and an *available for land application* basis. The as excreted value would represent the total mass of nutrient the animals would excrete and does not account for the fraction that isn't recoverable (for example if an animal spends time on pasture manure excreted would not be collected). The available for land application basis estimates the nutrient content of the manure after storage and the percent of the manure that would be collected. The as excreted estimate centered on using the number of animal spaces and type of animals produced in each county as described in the previous section and then utilizing the ASABE manure production standard to estimate the quantity and nutrient content individual animals would contribute. In all cases I took the ASABE standard and converted manure and nutrient excretion rates into a per day statistics (shown in table 3).

Table 3. Manure and nutrient excretion rates

Animal Species	Mass kg/head-day	N Excretion kg/head-day	P Excretion kg/head-day	K Excretion kg/head-day
Beef - Cow	31	0.19	0.044	0.14
Beef - Growing Calf	22	0.13	0.025	0.09
Finishing Cattle	27	0.15	0.020	0.10
Beef Bulls	31	0.19	0.044	0.14
Dairy Cow	63	0.41	0.070	0.11
Dairy - Calf - 150 kg	8.5	0.063	0.0105	0.046
Dairy - Heifer - 440 kg	22	0.12	0.020	0.09
Swine - Boar - 200 kg	3.8	0.028	0.0097	0.018
Swine - Sow	6.6	0.044	0.0128	0.029
Swine - Finisher	3.9	0.033	0.0053	0.014
Poultry - Turkey (females)	0.16	0.0025	0.00070	0.0010
Poultry - Turkey (male)	0.27	0.0041	0.00120	0.0020
Layers	0.09	0.0016	0.00048	0.0006
Broilers	0.10	0.0011	0.00033	0.0006

In the case of beef production animals were classified into one of four categories, beef cows, beef calves, finishing cattle, and bulls. Manure excretion is provided in the ASABE standard for beef cows, finishing cattle, and growing calves, but not bulls. I assumed that the excretion from beef bulls would be the same as a beef cow. In determining manure production from growing calves (< 1 year) the number of replacements was divided by two before multiplying by the manure production rate, this assumes that the birth of calves is uniformly

11

distributed throughout the year, no correction was made for replacements heifers over one year of age as this value represents heifers that would have been present on the farm every day of the year. Estimating manure production from dairy cattle was done in a similar manner. I assumed that a cow would be in milk for 305 days in the lactation and dry the remaining 60 days of the year. Swine manure production estimates follow directly from the estimated animal numbers and the manure excretion rates provided in table 3. Similarly, manure production estimates for layers and broilers follows from their estimate of animal numbers. Manure production was based on an estimate that half of market turkeys were toms and the other half hens, with manure excretion from laying turkeys assumed to occur at the rate to turkey hens.

One concern with this methodology is that it assumes that the composition of as excreted manure has not changed from 1924 through the present. At first glance this assumption is certainly questionable. However, using UDSA data Smil (2002) has shown that, with the exception of meat birds (broilers and turkeys) which showed drastic improvement, that feed conversion efficiencies have remained relatively unchanged. This would suggest that assuming relatively similar as excreted manure composition to be a reasonable initial estimate if diet remained constant. A similar sentiment is provided by Coffey (1996) who states "from a global perspective, swine production has not been a source of increased manure nutrient production," going so far as to suggest that improvements in nutrient use efficiency has even reduced nutrient excretion on a per pig basis. Specifically, Coffey (1996) states that feed conversion efficiently of grow-finish pigs has changed from 4 to less than 2.85 in top-producing pig herd, which on its own would result in nutrient excretion decreases of around 35%. However, animal diets have often changed dramatically over the last 100 years, often leading to significant improvements in animal performance, i.e., growth rates. Much of this improvement in animal growth would appear to be due to changes in diet that increased the quantity of feed the animal consumed, i.e., improved digestibility from smaller grind sizes and changes to more nutrient dense feed stocks. This change to greater nutrient density probably reduced the impact feed efficiency improvements had had on nutrient excretion as greater quantities of nitrogen and phosphorus were feed. More recently, improved understanding of the nutritional needs of the animal and the fraction of available nutrients within the feedstock have allowed nutritionists to better balance farm rations. Innovations such as phase feeding, the incorporation of industrial amino acids to improve nitrogen retention, as well as the inclusion of the enzyme phytase to increase phosphorus digestion have shown the potential to reduce nutrient excretion. Given these changes in animal feeding practices an increase in nutrient excretion from the animals would have been expected as the animals are confined and feed more nutrient rich feed stuffs; however, given the improvements realized in feed conversion efficiency and faster growth overall changes to nutrient excretion would have been minimized.

A second analysis where the manure was adjusted to an as applied basis by correcting for the percent of manure collected, nutrient losses during storage, and nutrient availability was also conducted. In this analysis it was assumed that swine manure would be stored in deep pits storages, beef feeder cattle would be raised on open feedlots, dairy farms would use a slurry manure system, turkeys and broilers would be raised on litter, and that layers would be housed in high rise facilities where manure collects below the cages and is stored until land application. I also assumed that beef cows, calves, and bulls would be raised on a mixture of open lots (30% of the time) and pasture (70% of the time), dairy calves and yearling were assumed to be on lots all the time, and swine boars and sows were assumed to use pit manure storage systems.

The first step in estimating manure production and nutrient content was to correct for nutrient and mass changes during storage. The percent loss that I estimated for different manure systems is shown in table 4. This table was calculated using the ASABE Manure Production standard for as excreted manure and the table of as removed production and characteristics table found at the end of the standard. No data was provided in the standard for beef cows, growing calves, bulls, dairy heifers and yearlings, or swine sows and boars. In these cases percent loss was assumed to be according to manure storage system. For example, since I assumed beef cows, calves, and bulls as well as dairy heifers and yearlings would be raised on open lots they were assumed to have the same mass and nutrient losses as finishing cattle raised on lots did (note, this does not account for the fact that beef cows, calves and bulls would only be on the lot 30% of the time). A similar approach was followed for swine sows and boards assuming they would have similar nutrient losses as swine finisher manure. The change in mass and nutrient loss was then multiplied by the daily excretion value and the percent of manure

that would be captured to estimate amounts available for land application. This is summarized in table 5. Nutrient availability was estimated based on Sawyer and Mallarino (2008) which suggested that all phosphorus and potassium would be available (based on soil test conditions) and that 50% of nitrogen in dairy and beef cattle (sum of three year availability – 35, 10, and 5% availabilities in 1st, 2nd, and 3rd years respectively, which takes nitrogen credits for subsequent years), 100% of swine manure (100% in first year), and 60% of poultry litter (55 and 5% in 1st and 2nd years respectively) N would be available.

Clearly, many approximations were needed to make these assumptions. In particular, animal housing and manure storages have evolved over time. Specifically, prior to 1974, when rapid installation of confinement animal operations was occurring, these assumptions are suspect. Prior to this the percent of manure expected to be captured would have changed drastically as operations moved from pasture based system to confinement housing, altering manure capture for land application. Specifically, pasture systems were a common part of both dairy and swine prior to the 1960s; this would have significantly reduced the percent of manure that was recoverable in some cases to almost 0% in summers as animals would be almost continuously out on pasture. Additionally, the alternative manure management systems would have different nutrients losses than those assumed in table 4.

Table 4. Manure mass and nutrient percent losses during storage.

Animal Species	Mass % Loss	TKN % Loss	P % Loss	K % Loss
Beef - Cow	72.2	41.0	0.0	6.3
Beef - Growing Calf	72.2	41.0	0.0	6.3
Finishing Cattle	72.2	41.0	0.0	6.3
Beef Bulls	72.2	41.0	0.0	6.3
Dairy Cows	-6.2	51.4	0.0	0.0
Dairy Calf	72.2	41.0	0.0	6.3
Dairy Heifer	72.2	41.0	0.0	6.3
Swine - Boar - 200 kg	0.0	14.5	7.7	30.7
Swine - Sow	0.0	14.5	7.7	30.7
Swine- Finisher	0.0	14.5	7.7	30.7
Turkey Litter	48.8	27.3	61.8	9.8
Layer Manure	65.9	65.3	24.4	32.2
Broiler Litter	80.0	32.2	63.6	54.3

Table 5. Manure and nutrient values after storage.

Animal Species	Mass kg/head-day	N Excretion kg/head-day	P Excretion kg/head-day	K Excretion kg/head-day
Beef - Cow	2.6	0.034	0.013	0.039
Beef - Growing Calf	1.8	0.023	0.0075	0.025
Finishing Cattle	7.5	0.089	0.020	0.094
Beef Bulls	2.6	0.034	0.013	0.039
Dairy Cow	67	0.20	0.070	0.110
Dairy - Calf - 150 kg	2.4	0.037	0.011	0.043
Dairy - Heifer - 440 kg	6.1	0.071	0.020	0.084
Swine - Boar - 200 kg	3.8	0.024	0.0090	0.012
Swine - Sow	6.6	0.038	0.012	0.020
Swine - Finisher	3.9	0.028	0.0049	0.010
Turkeys	0.11	0.0024	0.00036	0.0014
Layers	0.031	0.00056	0.00036	0.00041
Broilers	0.020	0.00075	0.00012	0.00027

Results and Discussion:

The first part of this analysis focuses on how manure excretion, manure nutrient availability for application, and crop nutrient demand has changed over time within Iowa (figure 1). Crop nutrient demand has increased greatly since 1924 (by approximately 4x, 6x, and 4x for N, P, and K respectively). The demand increased approximately linearly until around the 1960s when demand exploded, corresponding to increasing use of synthetic fertilizers. Demand continued to increase rapidly until around 1980 where it remained steady for approximately 20 years. Starting in the early 2000's demand again showed a steady increase for nitrogen and phosphorus, but demand for potassium remained relatively unchanged. One other trend of note in the nutrient utilization data is the four years where crop production was greatly reduced; these were 1983, 1988, 1993, and 2012. In three of these cases the reduced yields were due to drought like conditions (1983, 1988, and 2012) throughout much of the state and in 1993 it was due to flooding conditions. Similarly, reduced nutrient demands were seen in 1934 and 1935 (drought conditions) and in 1947 and 1956. However, nutrient utilization was much more volatile during the more recent adverse growing years than in the pre-1970's years. This is most likely due to the loss of crop diversity making nutrient demand much more dependent on a few crops and as a result more susceptible to adverse weather conditions during critical growth periods. Historically, nitrogen demand was about 50% from corn production with the other 50% split relatively evenly between small grain and grass hay production (figure 2a). However, corn now accounts for more than 90% of the nitrogen demand. Similar trends were seen for phosphorus and potassium demand (figure 2b and c); however in these cases nutrient demand is now dominated by the combination of corn and soybean demand.

Manure production throughout the years has been less variable (nutrient excretion increased by a factor of about 1.4x for all nutrients, while available nutrients increased by 3x, 2x, and 2x for N, P, and K). Nitrogen excretion exhibited a slow and steady climb, peaking around the 1970's. It then declined back to approximately 1924 levels, bottoming out in the 1990s. More recently nitrogen excretion has once again been on the rise. Available manure nitrogen has risen relatively consistently, corresponding to changes from beef and dairy production to swine production, leading to better capture of the manure and reduced nitrogen losses during storage. Phosphorus and potassium excretion and available for application showed similar patterns to that of nitrogen, a first peak in the 1970s and then an increasing trend over the last 15 years. This peak in the 1970s

corresponds to peaking of beef steer production in Iowa, where as the more recent increases corresponds to growth in the swine industry.

In general, I estimate that available nitrogen from manures has always been below the crop nutrient demand. This ratio actually peaked in the 1960s (when approximately 40% of N could be obtained from manure) and then decreases rapidly until the 1980s (approximately 22% of N could be obtained from manure). This change occurred due to the greatly increased demand for nitrogen for crop production. Since the 1980s this ratio has hovered around 22%. Similarly, phosphorus and potassium availability from manure has increased, but they too provide a lower percent of the nutrient demand required to support crop growth. As can be seen in figure 1 prior to 1970 I estimate that nitrogen, phosphorus, and potassium excretion in manures was actually greater than that the amounts harvested. This could occur if the animals were receiving a significant portion of the nutrients to support their growth from crops not accounted for in this analysis, presumably grasses while on pasture in these cases. In general, both available phosphorus and potassium initially trended closely with the amounts estimated to be harvested. Available nitrogen was significantly lower, indicating that crop production was either mining soil nitrogen or that green manures (plowing under of nitrogen fixing crops or cover crops) and the inclusion of legumes (alfalfas, clovers, field peas) in the rotations was supplying the required nitrogen.
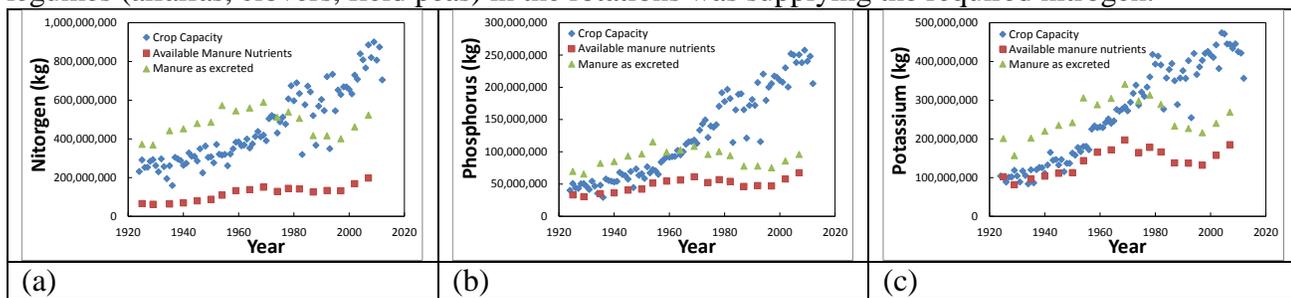

(a)   (b)   (c)

Figure 1. Trends in the crop nutrient utilization capacity and manure nutrients available for land application for (a) nitrogen, (b) phosphorus, and (c) potassium.
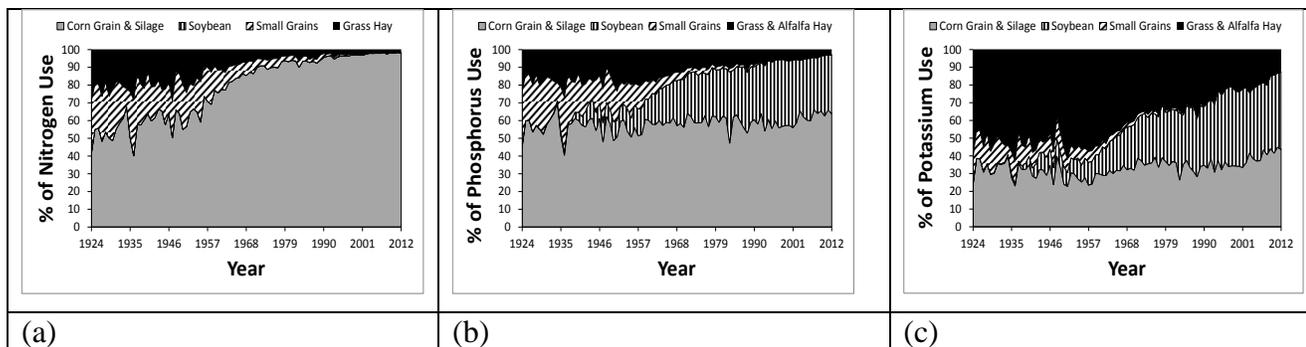

(a)   (b)   (c)

Figure 2. Estimated percent of crop nutrient for (a) nitrogen, (b) phosphorus, and (c) potassium for corn, soybean, small grains, and grass hay.

Another important aspect of evaluating changes in manure excretion and nutrient availability that is important to consider is how the contribution of available nutrients from different animal species has changed over time (figure 3). Dairy manure nutrients have consistently been a declining faction of the manure nutrients available for crop production. Similarly, manure nutrients available from beef cattle manures, although constant or even slightly increasing percent of all manure nutrients through the 1970s, has shown a steep decline ever since. This has allowed swine manure to become an ever increasing percentage of the manure available for crop production. As a result, there has been an increase in the percent of nutrients that are captured and available for crop production despite the fact that overall nutrient excretion beyond would have been expected from the change in nutrient excretion.
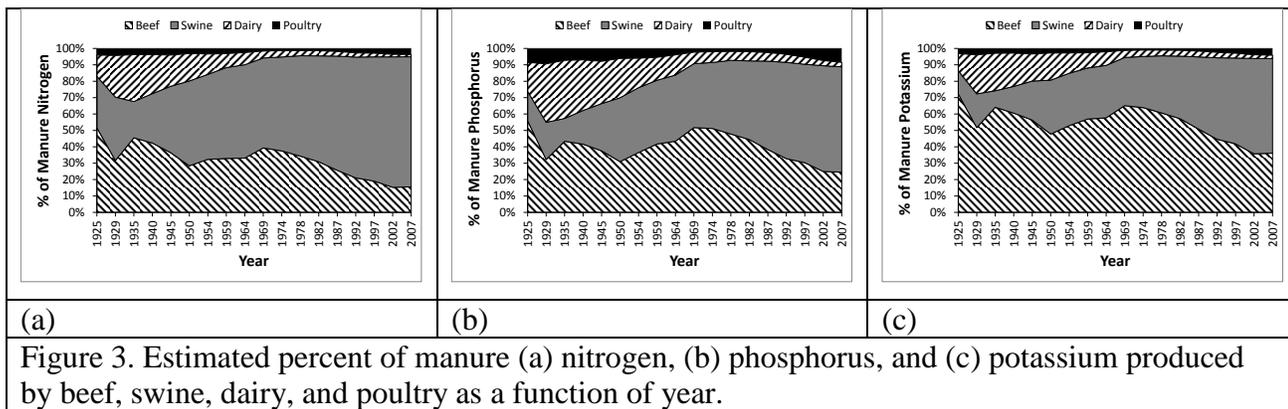
Figure 3. Estimated percent of manure (a) nitrogen, (b) phosphorus, and (c) potassium produced by beef, swine, dairy, and poultry as a function of year.

Our second question focused on the spatial distribution of nutrients at a county level and how this has changed with time. This analysis was performed to evaluate if within Iowa animal operations are congregating into specific regions as this could lead to the view of manure as a waste product in some areas while it would still be considered a resource at the state level. Specifically, this analysis will provide insight into what, if any regions may be in need of nutrient partitioning or extracting technologies that would make transport of the nutrients to manure poor regions more economically feasible. This analysis is repeated for each of the three nutrients of interest (nitrogen, phosphorus, and potassium) and for the census years of 1974, 1978, 1982, 1987, 1992, 1997, 2002, and 2007. Counties on the diagrams are color coded: counties that get the least (0-10%) of their required nutrient supply from manure are dark green; as a progressively greater percentage of nutrients could be supplied by the manure nutrients available within the country the shading changes to lighter greens, then yellow (60-70%), and eventually to a dark red (greater than 100% of required nutrient potentially available from manures).

In general, the same trends are seen for all nutrients. Counties in the northwest region are becoming progressively richer in manure nutrients in comparison to their crop nutrient demands. Specifically, for nitrogen I estimate that in the 1970s several counties (Adams, Taylor, Union, and Ringgold) could obtain more than 60% of their required nitrogen from manures. As nutrient demand continued to grow the percent that could be supplied by manures decreased; by 1992 only three counties (Sioux, Washington, and Dubuque) were estimated to be able to obtain more than 40% of their required nitrogen from manures. Since that time manure nitrogen has become more concentrated, such that Sioux county is now able to obtain more than 90% of its estimated nitrogen demand from manures. Several other counties (Lyon, Plymouth, O'Brien, Carroll, and Washington) are also obtaining a significant fraction of nitrogen from manures. However, there are also numerous counties (25) that now obtain less than 10% of their required nitrogen from manures. This illustrates that in Iowa concentration of animals and separation from crop production is becoming more prominent. Just as critical, the disappearance or reduction in the availability of animal manures is occurring in numerous other counties, indicating increases reliance on mineral fertilizers. Results of 2012 are somewhat skewed based on reduced crop production because of drought conditions throughout parts of Iowa.

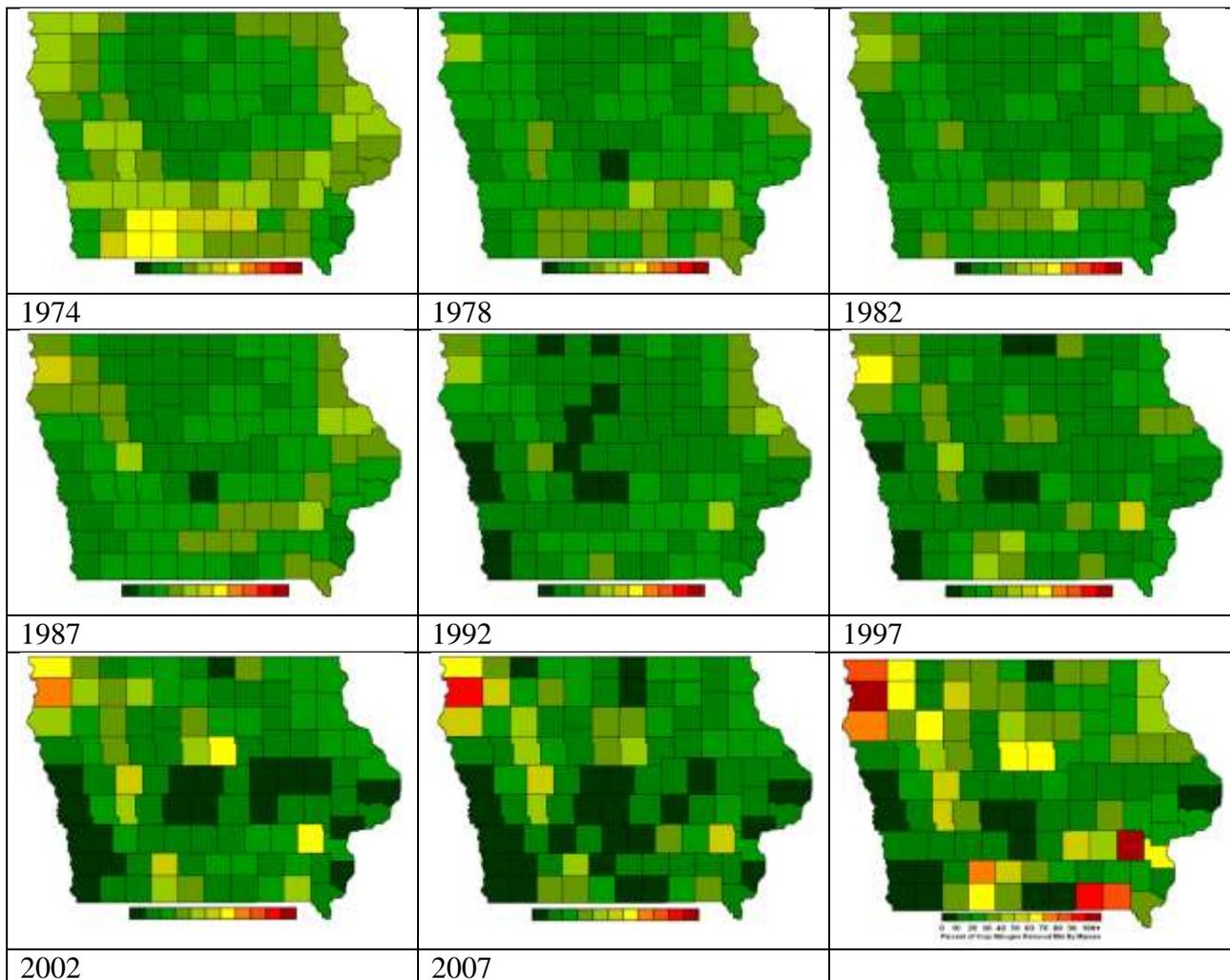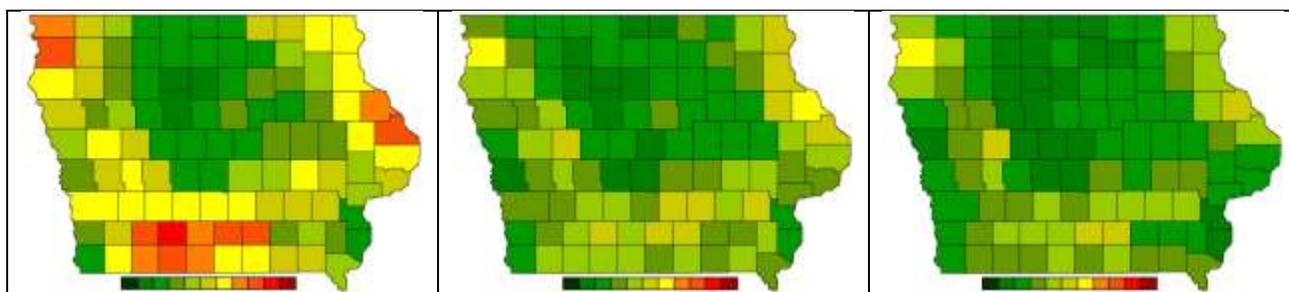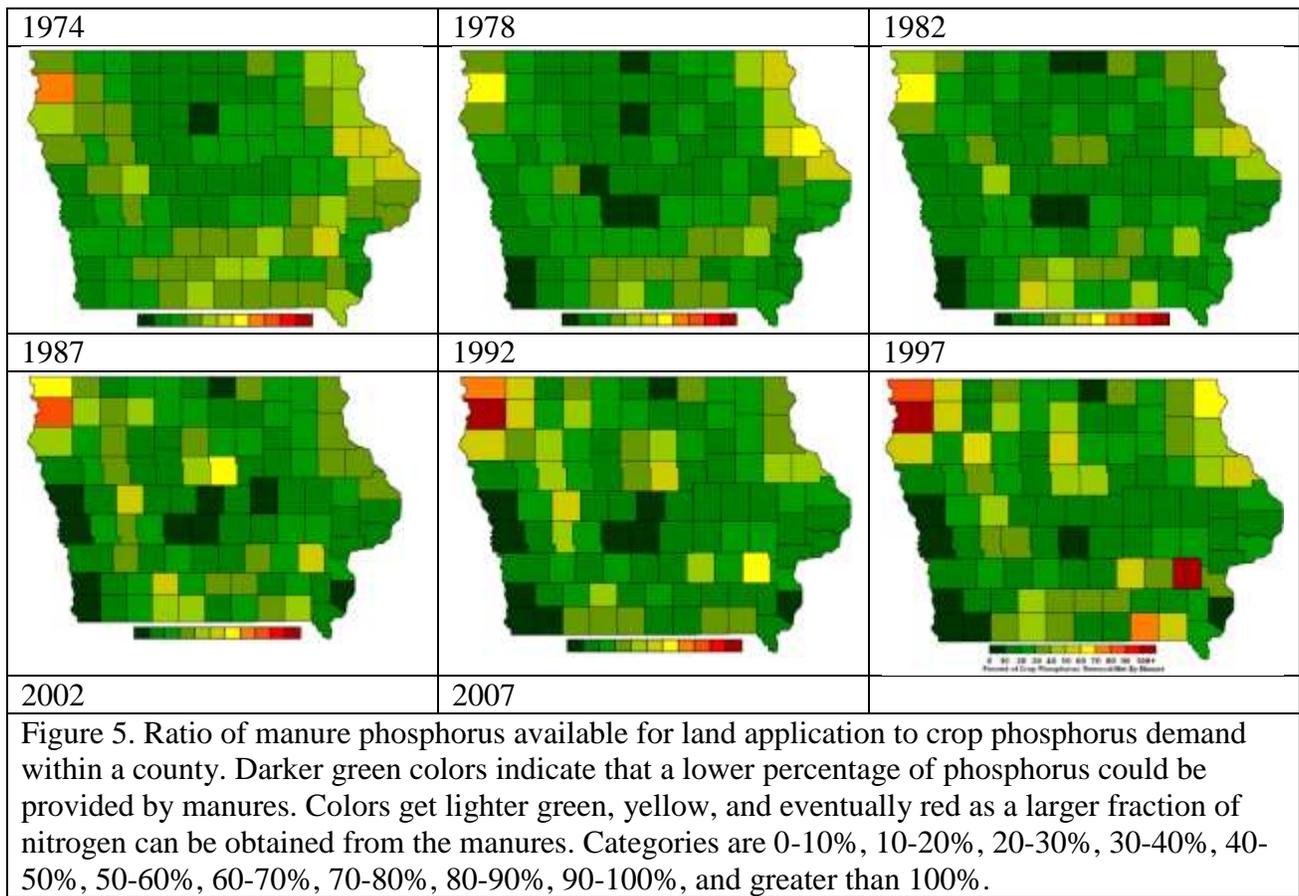|		
1974	1978	1982
1987	1992	1997
2002	2007	

Figure 4. Ratio of manure nitrogen available for land application to crop nitrogen demand within a county. Darker green colors indicate that a lower percentage of nitrogen could be provided by manures. Colors get lighter green, yellow, and eventually red as a larger fraction of nitrogen can be obtained from the manures. Categories are 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, 90-100%, and greater than 100%.

   In the first year mapped (1974) the Des Moines lobe was clearly evident as these counties were able to obtain a significantly smaller fraction of their required phosphorus from manures than the rest of the state. At this time many counties (especially those along the Mississippi and Missouri rivers and in South Central Iowa) were phosphorus enriched with most of these counties able to obtain greater than 60% of the required phosphorus from manures. By 2007 only five counties (Lyon, Sioux, Carroll, Washington, and Hardin) could obtain more than 60% of their required phosphorus from manures. Similar to nitrogen, many counties are also obtaining only small quantities of their required phosphorus from manures. Specifically ten counties are now able to only obtain 10% or less of their phosphorus from manures.

1974	1978	1982
1987	1992	1997
2002	2007	

Figure 5. Ratio of manure phosphorus available for land application to crop phosphorus demand within a county. Darker green colors indicate that a lower percentage of phosphorus could be provided by manures. Colors get lighter green, yellow, and eventually red as a larger fraction of nitrogen can be obtained from the manures. Categories are 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, 90-100%, and greater than 100%.

Conclusions:

These trends in manure nutrient availability in comparison to crop nutrient demand tend to indicate in most of Iowa nutrient assimilative capacity still far exceeds nutrient availability from manures in that county. However, there is strong evidence that animal production is concentrating and as a result becoming spatially separated from crop production areas. These trends indicate that opportunities for nutrient recovery and separation systems are starting to present themselves. As was shown, several areas are seeing increased availability of manure nutrients, and as such are nearing ratios where manure nutrient export from the county will be required to maintain nutrient balance. Also of note is that there are many areas in Iowa were these nutrients would be desirable as many counties are currently either mining soil reserves or becoming more reliant on mineral fertilizers to meet the nutrient needs of crops. This indicates that manure nutrient separation and nutrient recovery systems could provide a clear benefit as they provide opportunities to redistribute manure nutrients across the state, specifically from manure enriched counties to manure poor counties. Developing manure separation technologies that are economical and can be integrated into Iowa animal operations will be required to limit impact nutrient imbalances that separation in crop and livestock production present and to take full advantage of the nutrient resource manure provides.

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Objective 2. What Is It Worth?
The Economic Value of Manure Testing

Summary

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. To evaluate the monetary value of manure testing, an economic 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. 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.

Nitrogen (N) and Phosphorus (P) in animal manures are an important source of nutrients for crops. Loss of these nutrients can cause negative environmental impacts; 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. 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 or Midwest Plan Service. Manure nutrient contents vary widely from farm-to-farm and from year-to-year, such that over- and under-application of nutrients is likely to occur frequently when relying on values from these references.

Given the variability in composition, manure sampling and subsequent testing for nutrient composition is a critical component of proper management; however adoption of annual manure testing is relatively low, with only 20% of farms surveyed annually testing their manure's nutrient content annually. 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 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.

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. Thus, in our work 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.

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), 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.

As shown in Table 1, our work suggests that when applying manure at an N-limited rate, sampling manure before application increases profits by $8 to $28 ac^{-1}. When applying at a P-limited rate, additional profits of $1.50 to $9 ac^{-1} were estimated. The model 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.

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 on nutrient content. 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.

Table 1. Estimated value of the manure test for different manure type and crop rotations.

Manure Type and Crop Rotation	Pre-application		During Application	
	N limited ($ ac^{-1})	P limited ($ ac^{-1})	N limited ($ ac^{-1})	P limited ($ ac^{-1})
Swine slurry				
Corn-soybean	$8.07	$8.94	$1.37	$8.93
Corn-corn	$12.41	$4.30	$3.39	$4.29
Layer manure				
Corn-soybean	$13.22	$5.82	$4.01	$5.82
Corn-corn	$20.25	$2.74	$8.28	$2.74
Dairy slurry				
Corn-soybean	$12.03	$3.97	$11.10	$3.97
Corn-corn	$27.45	$2.00	$20.42	$2.00
Beef feedlot scrapings (earthen lot)				
Corn-soybean	$12.76	$2.89	$5.64	$2.89
Corn-corn	$20.32	$1.51	$11.12	$1.51

WHAT IS IT WORTH? THE ECONOMIC VALUE OF MANURE TESTING

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 (Steinfield et al., 2006). However, proper use of manure offers a redeeming virtue, because recycling of the 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 on commercial fertilizers are reduced (Honeyman, 1996). Achievement of these goals requires knowledge of manure nutrient contents so that appropriate application decisions are made; but often times application decisions are made based upon prior manure tests or reference values, such as those available from ASABE (ASABE Standards, 2005) or Midwest Plan Service (Lorimor et al., 2004). Manure nutrient contents vary widely from farm-to-farm and by 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 values from these references are relied upon.

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 impacting adoption, and that 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 be placed on documenting the economic value of manure testing.

Thus, the objective of this work was to determine, through economic modeling and utilization of expected value of information theory, the profitability (or lack thereof) of annual manure testing. Our hypothesis was manure testing improved farmer decision making, ensuring appropriate application rates, and in so doing, allowed the farmer to effectively capture the value of their 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 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 the farmer could utilize information gained from the test results, i.e., how having this information alters the farmer's nutrient management and affects farm profit. This is a complex topic, as almost limitless possibilities exist. In this evaluation, we assumed 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, and 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 its 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 United States. However, our model, which is available upon request, is readily adjusted to allow for analysis under different sets of assumptions. The impact of manure application being N- or P-limited and when sampling/testing was conducted on the value of the manure test were handled by evaluating all cases. Finally, the basis of this effort was that farms had intended to utilize their manure resources to support crop production. In cases where farmers have insufficient land to utilize all their manure resources, they could only extract this value if they could find buyers of their manure nutrients.

In addition to nitrogen, manures also contain phosphorus, potassium, and organic matter can also provide value to the farmer. Although this is the case, we assumed these factors were 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 nutrients do not contribute to the value of the manure, only that more accurate information on their concentration does not change immediate nutrient management decisions as 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 (figure 1) (Dodd et al., 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 the following years as long as appropriate future manure and fertilizer application decisions are made (though impacts on water quality may result). Consequently, greater knowledge of the exact P content of the manure does little to influence a producer's subsequent management of the crop. Similarly, testing results for potassium and organic matter would generally not affect fertility management decisions.
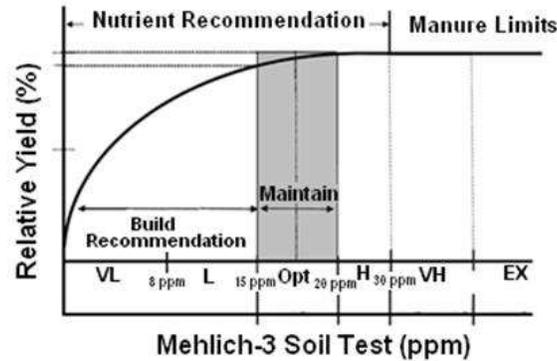

Figure 1. Conceptual schematic of crop response to soil test phosphorus level (based on Dodd et al., 2005). Our methodology was to generate an estimate of the profit that would have been made if the manure was assumed to have a "typical" composition, and then to compare this to the profit generated if manure nutrient composition was known. To make this evaluation, an economic model was developed as an Excel spreadsheet tool. The model compared the costs and proceeds of corn production. Performing this comparison required cost estimates of field activities, the cost of purchased inputs (herbicide and seed) (table 1, based upon Edwards et al., 2014), the sale price of corn, the cost of synthetic N fertilizer, 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 yield in corn-soybean and continuous corn rotations were set to 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-N (USDA, 2014) and the sale price of corn to $4.91 bu^{-1} (www.quotecorn.com, 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 (NAS-NRC, 1961) (Eq. [1]).

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

Where y is the percent of maximum yield, x the N application rate (kg N ha^{-1}), b a constant that estimates the amount of soil-derived available N, and c 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 Eq. (2) and (3) represent response curves for corn after soybean and continuous corn rotations respectively and assume that yield will be limited by nitrogen. These curves account for leaching and denitrification losses of N; however,

since they are based synthetic N, ammonia volatilization losses and first year available N were 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 (figure 2); applying this model to other areas requires the crop response to N for that location and crop rotation.

$$y = 100(1 - exp(-0.016611(x + 63.59444))) \quad (2)$$
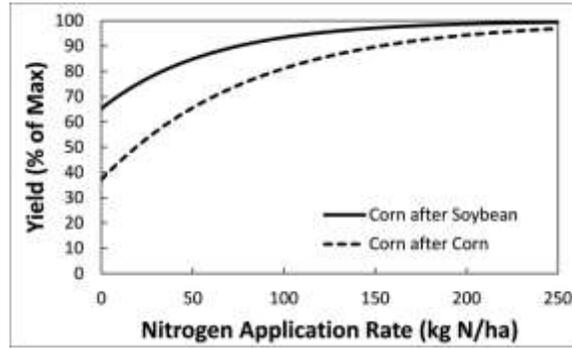$$y = 100(1 - exp(-0.012037(x + 38.57373))) \quad (3)$$

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

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

$$y = 0.1456x^{-0.32} \quad (4)$$
$$y = 0.0256x^{-0.157} \quad (5)$$

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

The MRTN value was determined using the Iowa State University Corn Nitrogen Rate Calculator (ISU, 2004). The manure application rate was calculated based on the desired N (or P) input and the expected N (or P) content of the manure, i.e., the concentration that would have been assumed if no sample was collected. The nutrient content was approximated to be 0.70% ± 0.16% N with 0.21% P for deep-pit swine manure, 1.85% ± 0.55% N with 0.60% P for layer manure, 0.30% ± 0.12% N with 0.13% P for dairy slurry, and 1.18% ± 0.39% N with 0.50% P for beef manure from an earthen lot (ASAE, 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 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.

Table 2. Summary of manure N & P concentrations, 1st year N availability, and ammonia volatilization used in assessing the value of the manure test.

	Manure N Content (%)		Manure P Content (%)	1st Year N Availability (% of N Applied)	Ammonia Volatilization (% of Applied N)
	Average	Standard Deviation			
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

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 "true" nutrient content. In so doing, it facilitates evaluation of different application strategies, such as applying insurance N, to account for the uncertainty in the manure's nutrient content. This is illustrated (figure 3) for the case of deep-pit swine manure applied to corn in a corn-soybean rotation. Appling 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. When we have uncertainty on our N content the response is more subdued and does not reach a maximum profit that is as high as that obtained for the no-uncertainty case, indicating that our lack of information has reduced our maximum expected profit. It also illustrates that the ideal nitrogen application rate did not change much (it was slightly lower) with the uncertainty in the nutrient content of the manure.
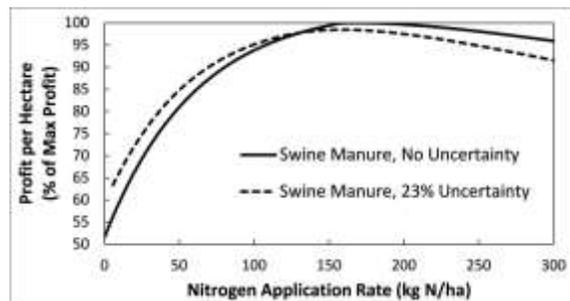

Figure 3. Evaluation of nitrogen application rate and the manure's nutrient content uncertainty (here uncertainty representing the coefficient of variation) on profitability per hectare.

In practice, two methodologies exist for sampling and testing manure. The first is to sample prior to manure application so that test results can be utilized to select manure application rates. The second is to sample manure during manure application and have test results afterwards to verify the amount of N applied. When the farmer chooses to sample their manure affects how the nutrient concentration information can be utilized. One potential issue with sampling prior to manure application is that changes to manure composition could occur 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 being what is actually applied; it has been subjected to the loss mechanisms that the additional storage time, agitation, transport, and land application may have caused, making the sample more representative. A limitation of this methodology 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 by 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 the N applied.

The process of valuing a manure test is illustrated in figure 4; (a) probability of different N contents in deep-pit swine manure, (b) estimated profit if manure application was based on assumed "standard concentration," (c) the profit if 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 the manure of unknown composition from the profit estimated for the same N content assuming the manure had been tested. For manures of low N content excessive manure application rates could results, thus we choose to limit 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.
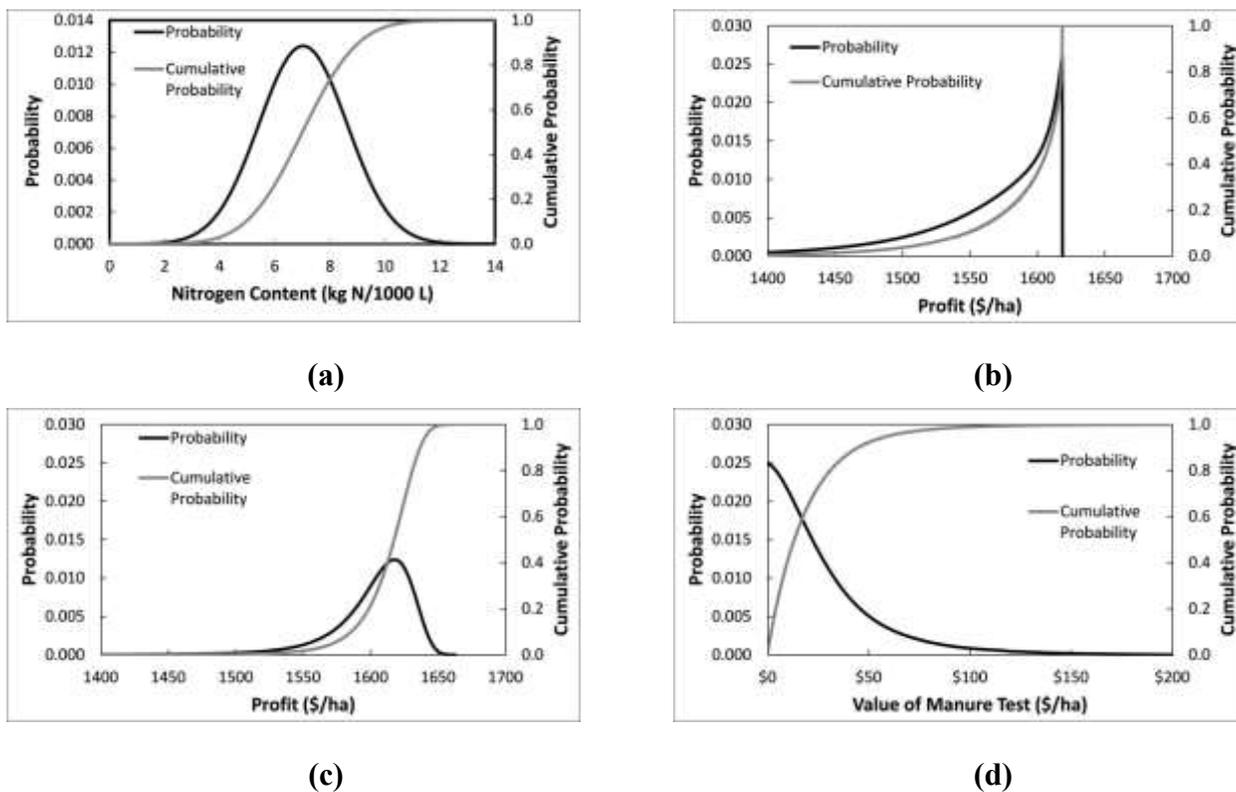

(a)

(b)

(c)

(d)

Figure 4. a. Probability of different nitrogen contents of deep-pit swine manure, b. probability of different profits due to the different nitrogen contents of the manure assuming standard rates c. the expected profit value applying manure of a known composition at the maximum return to nitrogen, and d. the 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 than the "book" value for N concentration. This increases the value of the manure test, as there is a greater probability of the gained information creating value by improving management options.

Similarly, manure testing offered more potential value in continuous corn rotations than in a corn-soybean rotation when manure application was N limited (table 3), i.e., if the manure application rate was limited by the amount of nitrogen the farmer could apply. This was 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-sampling was a better strategy when manure application would be limited based on N; however, if manure application was P limited sampling during application would be preferable. This occurred as our value is placed on N and thus creating a strategy to ensure a sufficient amount to support crop growth without wasting N is essential to maximize value. One interesting item is that the manure test was more valuable in corn-soybean rotations than continuous corn rotations when manure application was phosphorus 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	$10.61
Layer Manure	Corn-Soybean	$32.66	$14.37	$9.92	$14.37
	Corn-Corn	$50.04	$6.78	$20.45	$6.78
Dairy Slurry	Corn-Soybean	$29.72	$9.82	$27.44	$9.82
	Corn-Corn	$67.83	$4.93	$50.46	$4.93
Beef Feedlot Scrapings (Earthen Lot)	Corn-Soybean	$31.54	$7.13	$13.94	$7.13
	Corn-Corn	$50.20	$3.72	$27.48	$3.72

However, as some of the model inputs are quite variable, i.e., the price of corn and the price of fertilizer, understanding the sensitivity of these models is important for evaluating how factors impact the value of the manure test and circumstances that maximize the value a farmer gets from manure testing. In light of the above results, we focused our sensitivity analysis on pre-sampling for N limited manure applications and sampling during application for P limited manure applications. Swine manure was used to assess the sensitivity in the pre-sampling case (it was the manure with the highest available N to P ratio) while beef manure was used to assess the sensitivity in the during application sampling case (manure with the lowest available N to P ratio). The sensitivity analysis was conducted for the models by varying one 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, 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 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). Manure test value was positively related to the price of synthetic N because this meant that limiting wasted N provided value to the farmer. Similarly, manure test value increased as corn price increased because the value of applying sufficient N to achieve optimum yields increased, allowing supplemental N to more cases. The same logic applies to why 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 manure testing facilitating better use of the nutrient value. The manure test value also increased as the maximum corn yield potential increased because small changes in N application lead to greater yield response.

Table 4. Sensitivity of expected manure test value to corn price, the maximum corn yield, the cost of synthetic N, and the coefficient of variation of manure nitrogen content for swine manure to be applied at a nitrogen limited sampled prior to and during manure application for corn-soybean (CS) and corn-corn (CC) and for beef feed yard manure applied at a phosphorus limit sampled during manure application.

Item	Pre-application		During application		
	CS	CC	CS	CC	
Corn Price	0.07	0.10	0.01	0.01	$/ha fertilized / $/Mg corn
Maximum Corn Yield	0.92	1.68	0.92	0.64	$/ha fertilized / Mg corn/ha
Cost of Synthetic N	13.41	19.15	4.89	2.49	$/ha fertilized / $/kg N
Coefficient of Variation	1.00	1.92	0.22	0.11	$/ha fertilized / 1% change in COV

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 for an average and standard deviation of 0.79% ± 0.16% N. The N content for the current year was 0.92% N.

If no sample was tested, this operation would assume the manure had an available N content of 0.79%, the average of the previously collected samples. Using the pre-sampling technique and assuming manure application was N limited, the value of the manure test would be $30.96 ha^{-1}. Assuming it represents all the manure from this building, the overall value of the sample was $1,759 (farm would have applied manure to 56.8 hectares). This would represent 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 time of the farmer 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 over 112 ha, so the actual value of the test would be $1,589.

NON-PERFECT INFORMATION

Thus far, we have assumed that manure tests would provide perfect information. In reality, this is not the case, as some uncertainty on the true nutrient composition of the manure would remain. This leads to the question, how does our information being non-perfect impact the value of the manure test. This can be assessed by evaluating the difference in expected value of the test before sampling and then evaluating the value of the test again with some uncertainty remaining. This analysis was performed for deep-pit swine manure applied to a corn-soybean rotation at both a N limited (sampled prior to application) and P limited (sampled during application) basis to evaluate the impact. In both cases, (figure 5) greater benefit was gained from the initial reduction in N uncertainty than from perfect knowledge (steeper slop near the 0% reduction than 100% reduction portion of curve). Overall, these results indicate the lack of perfect information from manure sample results decreases the expected value of the manure test, but that even if we had 5% to 10% COV in the manures nutrient concentration remaining (a 56% to 78% reduction in uncertainty) we would recover 70% to 98% of the manure tests expected value. These reductions in uncertainty are typical for what would be expected from represented samples that were sent for nutrient analysis.
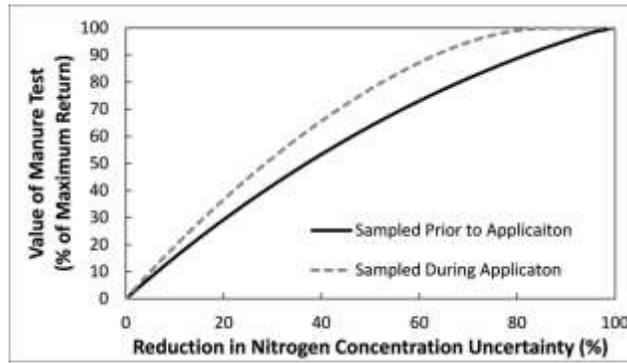
Figure 5. Evaluation of how non-perfect information, i.e., remaining uncertainty in the manure's nitrogen content impacts the value of the manure test for manure sampled prior to application applied at a nitrogen limiting rate and for manure sampled during application applied at a phosphorus limiting rate. Example calculations for deep-pit swine manure applied to the corn phase of a corn-soybean rotation.

As you may have noted, in this work we assumed either injection or immediate incorporation would be used for manure application. This methodology was assumed because it is a known best management practices for improving nitrogen use efficiency, and as a result is a common application strategy throughout Iowa for this reason and for odor control. However, some farmers still choose to surface apply their manure. This can occur for numerous reasons including being in a truly no-tillage system or utilizing irrigation methods such as pivots or sprinklers as the manure application equipment. Although putting a true value on manure testing in 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 non-perfect information. In the case of a liquid manure being broadcast with no incorporation Sawyer and Mallarino (2008) suggest between 10 and 25% of the N will be lost to volatilization, for an average of about 17.5. Although they do not provide a statistical distribution about this value, assume they are providing a 95% confidence interval. Then our uncertainty in the amount of nitrogen from just potential volatilization would be at least 5%. Assuming we were working with deep-pit swine manure this would mean we have reduced our nitrogen application uncertainty by 80% and would still recover approximately 90% of the manure tests value. However, other uncertainty, such as the variability of the manure's composition as it comes out of the storage, variation in manure application rate as we are applying, and variation in the first year nitrogen availability might reduce this further increase 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 variability in conditions mean the farmer often lacks information that could be utilized to make a more informed decision. Sampling and testing different parameters provides farmers with more information that 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 we recommend that if manure is being applied at an N-limited rate that the sample be collected prior to application to be used in determine the manure application rate. 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 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 a nitrogen-limited rate, sampling manure prior to application increases profits by $20 to $68 ha^{-1}. When applying at phosphorus-limited rates, additional profits of $4 to $22 ha^{-1} where estimated. We also found manure sampling is inherently more valuable in manure management systems that have greater variability in manure nutrient content, such as out-door storages 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 to estimate first-

28

year nitrogen availability all impact the value of the manure test as it means our manure sample estimate is now non-perfect, as additional variability remains.

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Objective 3. Evaluation of the Economic Constraints on Nutrient Partitioning Systems to Reduce the Costs of Land Application of Manures

Summary
Manure can serve as either a resource that is applied to crops to provide nitrogen, phosphorus, trace nutrients, and build soil organic matter or a waste that the producer must dispose. The perspective of whether manure is a waste or resource is often based on the perception of if the cost to utilize (transport and land apply) the manure as a fertilizer is more or less expensive than purchasing commercial, mineral fertilizers. One method that has been proposed for improving the transportability of manures is to perform a treatment where nutrient enriched and nutrient depleted fractions are created. The nutrient enriched fraction can then be more economically transported greater distances from the farm. In this work, information on how different manure nutrient partitioning strategies of differing effectiveness would impact the costs of manure application was evaluated. This analysis provides information on the amount of money an operation could potentially put towards implementing the manure treatment technology as it must be equal to or less than the reduction in manure application costs to be an economically viable option. Two existing manure treatment systems, a screw press separator and a decanting centrifuge, are then utilized as examples to evaluate their cost feasibility for various sizes of swine and dairy operations applying their manure at either nitrogen or phosphorus limited rates. The results indicated that when applying manure at nitrogen limited rates, neither treatment technology was cost feasible for any of the operation sizes investigated; however, when applying manure at a phosphorus limited rate the decanting centrifuge was cost feasible for larger operations (more 12000 head capacity of swine or 1000 dairy cows). These results provide a quick method to evaluate the cost feasibility of different manure nutrient partitioning technologies and the performance requirements these systems would have to achieve.

Keywords: Manure treatment, manure application costs, land application costs, nutrient separation, nutrient partitioning, United States of America

INTRODUCTION
Driven by world-wide population increases, growing incomes, and increased urbanization, society has experienced a marked and rapid dietary transformation; specifically increases in per capita demand for animal proteins (meat, milk, and eggs) (Smil, 2002). These increases in global animal protein consumption have, and will continue to, markedly impact agricultural systems. Historically, these changes resulted in increased farm sizes (more acres per farm or animals per farm), an operational separation of crop and livestock production as farms became more specialized, and an increased use of animal confinement facilities instead of pasture based systems for animal production. These alterations facilitated installation of on-farm mechanization, allowed an economy-of-scale, and typically resulted in greater production efficiencies. However, they have also resulted in greater concentration of manures over smaller spatial regions, and with this separation a dichotomy in how manure is viewed, i.e., as a waste or a resource. It has been recognized for years that manures can serve as valuable soil amendments due to their potential contribution to improved soil quality and tilth as well as the nutrients (nitrogen, phosphorus, potassium, etc.) they can supply. However, the distance that manure can be economically transported has practical limits. That is, due to the relatively lower nutrient contents and higher moisture contents of manures as compared to commercial fertilizers, the costs of transporting manures away from centers of animal production quickly increases, such that they are more expensive than purchasing commercial mineral fertilizers. This can lead to the perspective that manure is a waste product that needs to be

treated and disposed of, rather than a resource offering a means of providing natural fertility. The debate over how manures should be managed has only intensified as demand for animal protein and agricultural sustainability has increased.

The nutrient density of the manure is one of the most important factor influencing transportation costs. As the largest part of the manure slurry is water, it is natural to consider separation and partitioning strategies that divide the slurry into different fractions. 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. However, if a producer is going to add a nutrient partitioning technology to their manure management system, the costs associated with the installation and use of the system need to be recovered. Potential economic benefits associated with 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), or potentially the recovery of a bedding product that could be recycled for on farm use. Although all three of these factors could be important in justifying the added costs of the nutrient partitioning/separation systems, the work presented here will only focus on the cost modification occurring to manure transport and land application.

Thus, the objective of the work presented here is to evaluate how the costs to land apply manure slurries would be altered by achieving different levels of nutrient partitioning. In so doing, the constraints on the costs that can be used to construct and operate the nutrient separation technology with various efficiencies will be better understood. Additionally, this work provides a means for 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. To better demonstrate this application, two existing nutrient partitioning technologies, a screw press separator and a decanting centrifuge, were used as examples to evaluate under what situations they would reduce the costs of manure application.

PURPOSE

An analysis of manure production versus crop utilization capacity at a county level in Iowa indicates that in most cases there is sufficient capacity to utilize all manure nutrients (only manure phosphorus in Sioux county exceeded the estimated crop utilization capacity, though manure nitrogen was able to supply a little over 90% of the crops nitrogen need as well). However, despite not currently having excess manure nutrients in any counties, there has been a trend of increasing manure nutrients as a fraction of crop utilization capacity in a handful of counties and a drastic decrease in the remaining counties. This spatial pattern indicates that nutrient imbalances are developing within Iowa. Numerous counties are progressively becoming manure poor while several counties may soon view manure as a waste as land application area is harder to find. This indicates that if economically viable nutrient partitioning strategies are developed they could be utilized to better distribute these manure nutrients to other counties were they could be put to use to support crop production. Thus, understanding the economics of nutrient treatment technologies can play an important role in alleviating some of these nutrient imbalances and ensuring that manure is utilized as a resource and in an environmentally responsible manner.
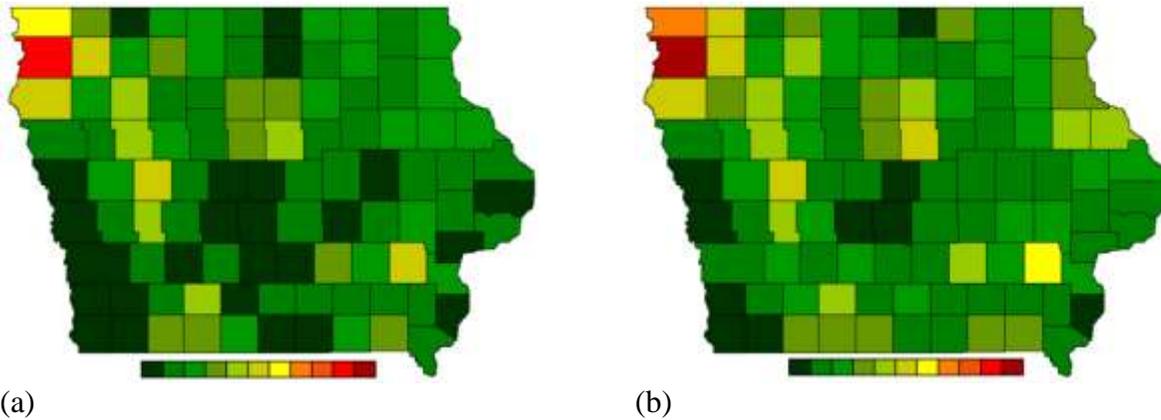
Figure 1. Evaluations of county levels (a) nitrogen and (b) phosphorus availabilities from manure as a percentage of the county's nutrient utilization capacity for crop production. Categories are in increments of 10%, i.e., 0-10%, 10-20%, 20-30%, etc., with the final category being greater than 100%.

In addition to these concerns at the county level, nutrient distributions at the farmstead level are also an important factor. Farmstead level nutrient distribution issues are generally thought to result from the operational separation of crop and animal production, as this leads to increased use of feedstuffs that are imported to the farm, rather than grown on site. As a result there is a flux of nutrients imported onto the farm. Nutrient imbalances can also occur on integrated operations due either to lack of land available for manure application or from poor distribution of the manure nutrients, i.e., annually utilizing the same fields for manure application and utilizing nutrient application rates above crop removal. These farm level nutrient imbalances are typically much more important than the county level imbalances in evaluating how manure management and application decisions are made. For example, a study of 33 confinement animal feeding operations in Nebraska indicated that 25 of the operations experienced significant (greater than 50% difference in managed inputs and outputs) nitrogen imbalances while 17 had significant phosphorus imbalances, with the majority of this imbalanced believed to be caused by the import of animal foodstuffs (Koelsh and Lesoing, 1999). This indicates that treatment techniques that facilitate the movement of manure nutrients back to the locations where the animal foodstuffs are produced could facilitate improved nutrient utilization and potentially reduce impacts on water quality.

MODEL DEVELOPMENT
The first objective of this work was to develop a relationship to describe the costs associated with applying manure and the manure application rate. Our data for this is from Mulhbauer et al. (2008). In addition to the land application costs, an additional 0.0002 $/L-km for every additional km the manure is transported away from the farm beyond the first km was estimated (Mulhbauer et al., 2008). Costs on a specific farm are from necessity much more complex than these assumptions as in many cases they are strongly influenced by distance from the barn to the field driveway, as well as variables like the size of the field, and how a drag hose could be routed or the path that tank wagons would have to take to get the manure from the storage to the land application area, or even the number of times the drag hose would have to be set and moved to cover the application area.
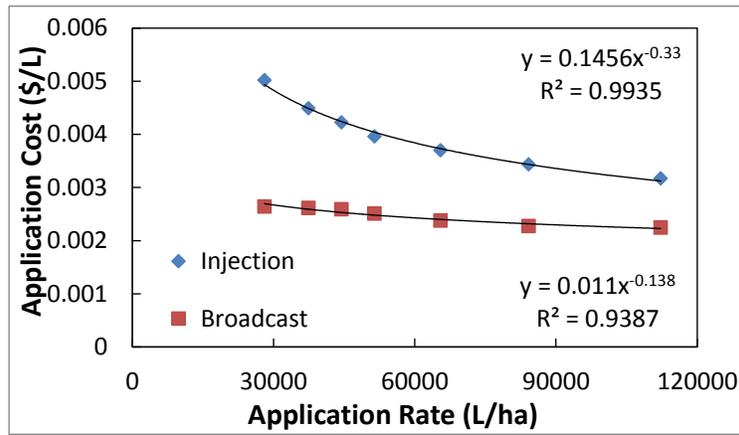
Figure 2. Impact of manure application rate on manure application cost per litter of manure; also illustrated is the differences between broadcast application and manure injection.

In addition to cost data, information on how the manure will be distributed, i.e., the transport distance from the farm, is needed to estimate the manure transport costs. This is dependent on the availability of land for manure application and the amount of manure (in terms of total nutrient need) that can be applied. These values most certainly vary from farm-to-farm as they depend not only on items including topography, road placement, locations of streams and drainages, and variables of the like, but also on how much land the farmer owns, the willingness of neighbors to either accept or buy manure nutrients, the crop rotations being utilized, and the yield potential of the crop. As the purpose of the analysis here is to gain general insight into what the requirements are to make these nutrient partitioning practices economically feasible, not to perform an analysis for a specific farm, I make general assumptions about appropriate manure application rates and the availability of land for manure application. In this analysis, I assumed that 60% of land around the animal production facility is utilized for crop production, and that approximately 50% of the land was to be planted to corn and the remaining 50% to soybean, with manure application only occurring to the corn phase of the rotation. The manure application rate was such that 168 kg N/ha (150 lbs N/acre) N was supplied, or in phosphorus limited cases about 35 kg P/ha (31 lbs/acre).

As the objective of this work was to evaluate how the partitioning of nitrogen (or phosphorus) in the manure into different fractions, i.e., a nutrient enriched and a nutrient depleted fraction, altered the costs associated with transporting and land applying the manure, the second item that needed to be addressed was a means of characterizing the effectiveness of the nutrient partitioning system. Specifically, in terms of land application we are most interested in evaluating how partitioning some percentage (E_t) of the total nitrogen or phosphorus into some volume fraction of the manure (R_f) would impact the land application costs. Based on the needs of this analysis, it is best described by two variables, the simple separation index (shown as equation 1) and the ratio of the volume of the enriched fraction to the total slurry volume (equation 2). In equation 1, U is the quantity of the nutrient enriched fraction (L), M_c is the nutrient concentration of the enriched fraction (mg/L), Q is the total quantity of manure slurry (L), and S_c is the nutrient concentration of the untreated slurry, thus the simple separation index describes the percent of nutrient captured in the enriched fraction.

$$E_t = \frac{U \times M_c}{Q \times S_c} \qquad (1)$$

A second index often used in describing nutrient separation systems is the ratio of the concentrated volume to the original volume of manure (equation 2); this is often termed the volume separation index. In some cases it is useful to combine these two indices such as was done by Svarovsky (1985) and is shown in equation 3. This gives what has been termed a reduced separation index; however, for our purposes here it is most convenient to

35

use indexes 1 and 2 separately as they can be used to calculate nutrient concentrations in the nutrient enriched and nutrient depleted fractions.

$$R_f = \frac{U}{Q} \qquad (2)$$

$$E_t' = \frac{E_t - R_f}{1 - R_f} \qquad (3)$$

The original cost of manure transport and land application can then be compared to the costs of transport and land application when differing levels of manure treatment were obtained. This then gives the performance and cost relationship the nutrient partitioning systems would have to achieve to be a viable option to implement in the farm's manure management systems.

RESULTS AND DISCUSSION

In this section the results of the model will be presented for four example cases. A swine finishing operation applying manure at a nitrogen limited rate, a swine finishing farm applying manure at a phosphorus limited rate, a dairy farm applying manure at a nitrogen limited rate, and a dairy farm applying manure at a phosphorus limited rate.

Swine Finishing Operations – Nitrogen Limited Manure Application

Assume a 4,000 head grow-finish operation. This operation completes 2.5 production cycles per year and has pigs that excrete manure at a rate and nutrient content in line with those suggested in the ASABE manure production and characteristics standard (2005), i.e., 4.5 L/head-day and the manure has nitrogen and phosphorus contents of 0.47% N and 0.18% P (approximately 40 lbs N and 15 lbs P per 1,000 gallons) after storage in a deep pit. Thus at this operation 6,570,000 L of manure are generated per year and 30,879 kg of N and 11,826 kg of P that need to be land applied. Assuming manure application occurs at a nitrogen application limit and 168 kg N/ha are applied (roughly the recommendation for corn following soybean in Iowa), then 184 ha of land application area are required for manure application. The resulting manure application rate would be approximately 35,745 L/ha. Using our previous assumptions (50% of farmable land in corn and 60% of the land farmable) then 613 ha of total land area would be required. Based on these calculations, this example farm would apply about half of the manure within 1 km of the farm and the other half would be applied within the second km. Manure applied within the first kilometer would cost about $0.00458/L for application, while manure within the second kilometer would cost about $0.00478/L. Of the manure, 3,368,857 L would be applied at the $0.00458/L rate and the other 3,201,143 L at the $0.00478/L rate; thus total cost for land application would be $36,475 or about $198.44 a hectare or $0.004675/L.

The results of this analysis (figure 3) indicated that nutrient partitioning techniques could lower the cost of land application with the effectiveness of nutrient partitioning (in terms of total nutrient capture and the volume these nutrients are concentrated in) resulting in different cost reductions. On this graph, the x-axis represents the simple separation index (shown as equation 1) and the y-axis represents the estimated cost of land application, in dollars per liter of manure applied. Each series on this graph represents that percent of total manure volume that ends up in the nutrient enriched fraction. In general, the cost reductions were minimal until either extraction efficiency (the percent of total nutrients captured) was relatively high or nutrients were extracted into a relatively small volume. This figure provides information on what a farm could pay for the nutrient partitioning process, for instance if they obtained equipment that could partition 60% of the nitrogen in 10% of the manure mass it would reduce the application cost by approximately $0.00068 per L, or the manure application bill by $4,460 per year.
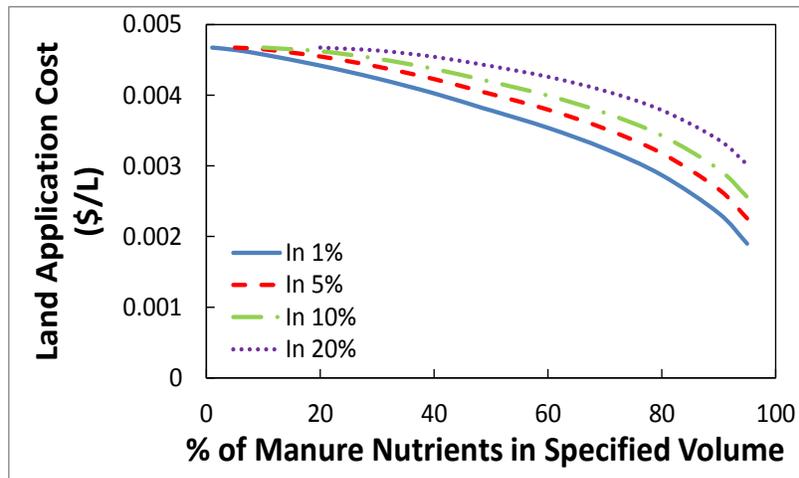
Figure 3. Evaluation of a nitrogen partitioning technology with differing performances to impact the costs of transport and land application of the manure.

A similar analysis was then conducted for a swine finishing operations with 8000 head, 12000 head, and 25000 head (one-time capacities) of finishing hogs to evaluate the impact operation size had on these results. That was, operations of differing sizes were investigated to evaluate the potential economy of scale for utilizing more advanced manure treatment methods. In this case the absolute cost of manure transport and land application are not important, but rather the reduction in land application cost that would be achieved with three different nutrient partitioning scenarios (50%, 70%, and 90% of the nitrogen partitioned into 10% of the manure volume). Thus, in this case the cost of manure transport and land application post nutrient partitioning was subtracted from the manure transport and land application cost that would have occurred if no nutrient partitioning technology was used. In all three cases an economy of scale was evident (figure 4). In the case of 90% of the manure nitrogen being partitioned into 10% of the manure volume the cost reduction per litter of manure applied was increased by approximately $0.000009 per every 1000 head increase in finishing capacity, or approximately 0.5% per every 1000 head increase in finishing capacity. In the case of partitioning 70% of manure nitrogen into 10% of the manure volume an increased savings of $0.000005 per liter per every 1000 head increase in finishing capacity would be achieved. This again works out to approximately a 0.5% reduction in cost per liter of manure applied for every 1000 head increase in finishing capacity. Finally, in the 50% of nitrogen in 10% of the manure volume case only resulted in approximately a 0.2% increase in cost savings for every 1000 head increase in finishing capacity.
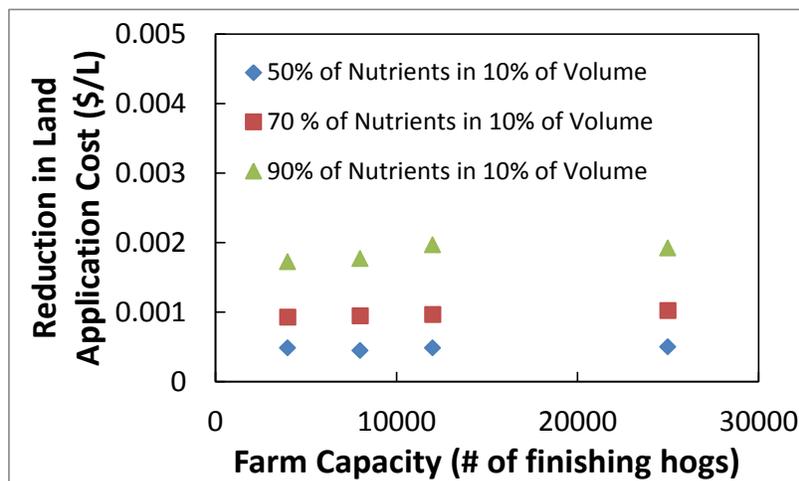

Figure 4. Evaluation of a nitrogen partitioning technology with differing performances to impact the costs of transport and land application of the manure.

Swine Finishing Operations – Phosphorus Limited Manure Application

Assume farm conditions are similar to those used previously, but in this case manure is to be applied based on a crop phosphorus removal rate. In this case the crop removal rate was assumed to by 35 kg P/ha. Manure application was estimated to be slightly more expensive than the nitrogen limited case as more land was needed to apply at a phosphorus based level than when the nitrogen based rate was utilized. The relationship between how costs decreased with different nutrient partitioning strategies was similar to those seen for nitrogen (figure 5). Similar economies of scale were also seen with the potential savings obtained from treatment increasing by about 0.5% more for every 1000 head of pig capacity added to the farm.
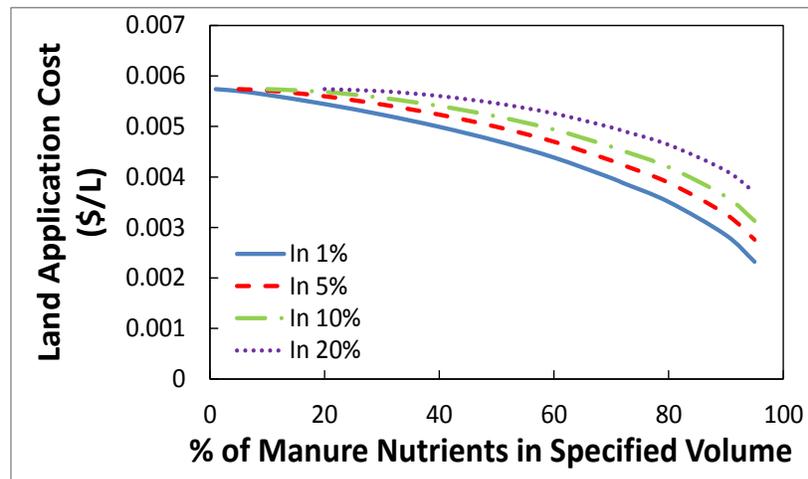

Figure 5. Evaluation of a phosphorus partitioning technology with differing performances to impact the costs of transport and land application of the manure.

Dairy Operations – Nitrogen Limited Manure Application

Assume a 2000 head dairy operation. This operation has dairy cows that excrete manure at a rate and nutrient content in line with those suggested in the ASABE manure production and characteristics standard, i.e., 67 L/head-day at 0.3% N and 0.13% P (approximately 25 lbs N and 11 lbs P per 1,000 gallons) (ASAE, 2005). Thus this operation generates 48,910,000 L of manure per year and with it 146,730 kg N and 63,583 kg P. Assuming manure application occurs at a nitrogen application limit and 168 kg N/ha are applied (roughly the recommendation for corn following soybean in Iowa), then 873 ha of land application area are required for manure application. The manure application rate would be approximately 56,000 L/ha. Using our previous assumptions (50% of farmable land in corn and 60% of the land farmable) then 2911 ha of total land area would be required. Based on these calculations, this example farm would have to transport some of its manure beyond 3 km. In this case, manure applied within the first kilometer would cost about $0.003947/L for application, manure within the second kilometer would cost about $0.004147/L, within the third kilometer would cost $0.004347/L, and within the fourth kilometer would cost $0.004547/L. On average manure application would cost about $0.004245 per liter.

An analysis of how different nutrient partitioning efficiencies (in terms of both total nutrients captured and the volume they are concentrated into) would impact the cost of land application is presented in figure 6. On this graph, the x-axis represents the simple separation index (shown as equation 1) and the y-axis represents the estimated cost of land application, in dollars per liter of manure applied. Each series on this graph represents that percent of total manure volume that ends up in the nutrient enriched fraction In general, the cost reductions were minimal until the extraction efficiency (the percent of total nutrients captured) was higher than about 80%, at which point the costs dropped more quickly. Again, this figure provides information on what a farm could

38

pay for the nutrient partitioning process, for instance if they obtained equipment that could partition 60% of the nitrogen in 10% of the mass it would reduce the application cost by approximately $0.000642 per L, or the manure application bill by $31,415 per year. If 90% of the nitrogen could be captured in 10% of the manure volume, then the producer would save approximately $0.001671 per L, or about $81,727 per year.

A similar analysis was then conducted for dairy operations with 250, 1000, and 5000 head to evaluate the impact operation size had on these results. In this case the absolute cost of manure transport and land application are not important, but rather the reduction in land application cost that would be achieved with different nutrient partitioning scenarios (50%, 70%, and 90% of the nitrogen partitioned into 10% of the manure volume). Thus, in this case the cost of manure transport and land application post nutrient partitioning was subtracted from the manure transport and land application cost that would have occurred if no nutrient partitioning technology was used. In all three cases an economy of scale was evident and visually more important than it was in the case of swine operations. In the case of 90% of the manure nitrogen being partitioned into 10% of the manure volume the cost reduction per liter of manure applied was increased by approximately $0.00007 per every 1000 head increase capacity (figure 7), or approximately 4.7% per every 1000 head increase in finishing capacity. In the case of partitioning 70% of manure nitrogen into 10% of the manure volume an increased savings of $0.00004 per liter per every 1000 head increase in capacity would be achieved. This again works out to approximately a 5% increase in cost savings per liter of manure applied for every 1000 head increase in finishing capacity. Finally, in the 50% of nitrogen in 10% of the manure volume case resulted in approximately a 5% increase in land application cost savings for every 1000 head increase in capacity, or about $0.00002/L for every 1000 head increase, resulted.
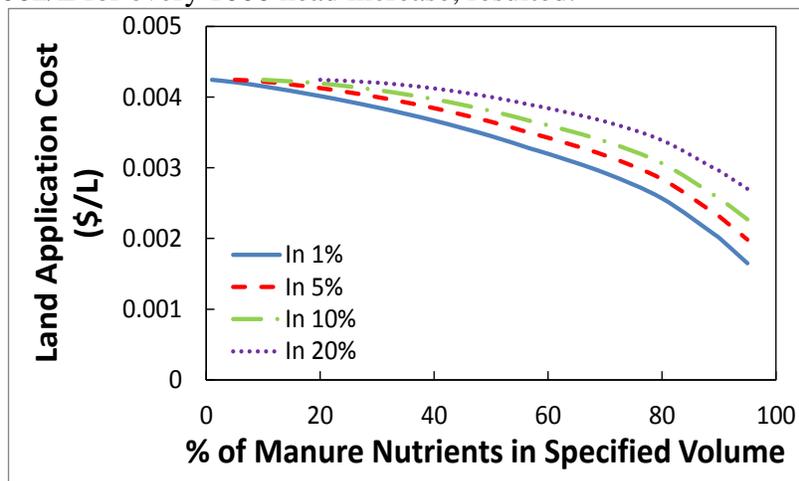

Figure 6. Evaluation of a nitrogen partitioning technology with differing performances to impact the costs of transport and land application of the manure.
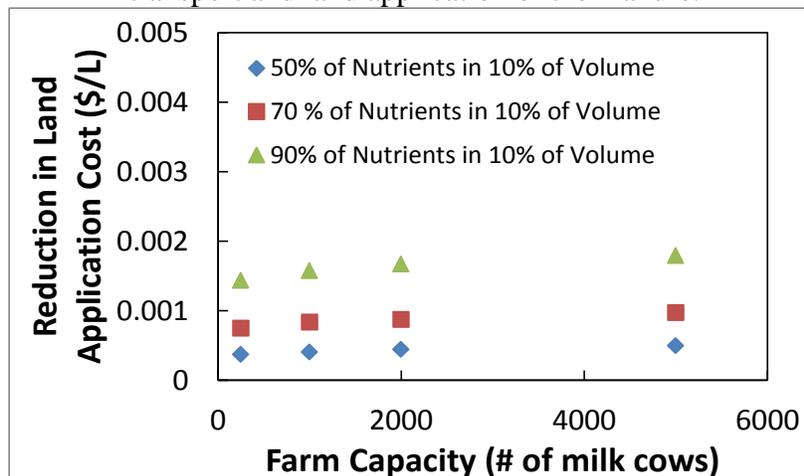

39

Figure 7. Evaluation of a nitrogen partitioning technology with differing performances to impact the costs of transport and land application of the manure from different sizes of dairy farms.

Implications

Annual costs of utilizing different nutrient partitioning strategies includes power costs, maintenance costs, personal costs to run the equipment, the cost of any expendables such as acid, polymers, or metal salts, and the capital costs of purchasing and installing the equipment. Example costs for operating two types of separators, a screw press and a decanting centrifuge, were calculated by Moller et al. (2000). In their calculations they included costs for purchasing and operating the separation equipment, but did not relate the costs of operating the separation system to changes in the costs associated with transporting and land applying the treated slurry. In this section of the manuscript I will perform a similar analysis to that presented by Moller et al. (2000) and link that to the changes in land application cost data presented within this manuscript utilizing estimated levels of separator performance available from literature. The estimated capital costs of operating the separator systems as a function of the volume of manure treated indicated that cost per L of manure treated decreased rapidly to about 25 million liters and was then relatively constant thereafter (figure 8). This figure matches that of Moller et al. (2000) and assumes the separation system has a fixed life of seven years regardless of the amount of manure it is used to treat.

A second important consideration is how effective the separator is at partitioning nutrients into different fractions. A review by Hjorth et al. (2010) suggests that when a screw press separator is used 15% of the nitrogen (standard deviation of 17%) and 17% of the phosphorus (standard deviation of 14%) can be concentrated into 11% of the manure volume (standard deviation of 15%). In the case of a decanting centrifuge 16% of the nitrogen (standard deviation of 8%) and 71% of the phosphorus (standard deviation of 14%) can be captured in 14% of the manure volume (standard deviation of 7%). In general, the two separation systems performed similarly for nitrogen, but drastically different for phosphorus. The question then becomes would either of these separation options be economically feasible on either the swine or dairy farms examples evaluated within this manuscript?
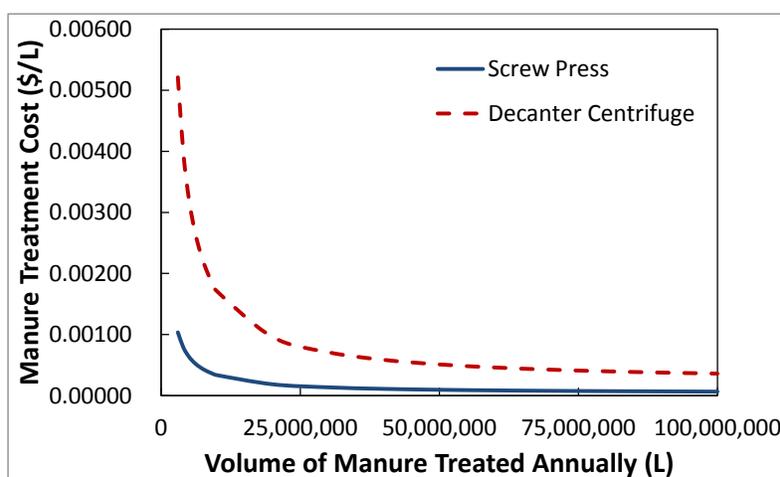

Figure 8. Estimated price of treatment per liter of manure based on manure treatment volume.

In short, the answer was no, at least for the nitrogen cases. Every farm size and separator combination evaluated resulted in a manure treatment costs that were between 3 and 620 times more expensive per liter than the savings that could be achieved in manure transport and land application costs. However, these results are very much dependent on the distance that both the concentrated and nutrient depleted fractions would need to be transported. These results were not unexpected as neither technology was able to remove and concentrate a substantial portion of the manure nitrogen. The results for phosphorus separation were more interesting; in this case, the decanter centrifuge was more cost effective than the screw press separator in all cases due to its much

40

more successful separation of phosphorus into the nutrient enriched fraction. The decanter centrifuge performance was sufficient to reduce the costs associated with land application in several cases, these included dairies larger than 1000 head and swine farms larger than 12000 head capacity.

Conclusions

The nutrient density of the manure is one of the most important factors influencing transportation costs. As the largest part of the manure slurry is water, it is natural to consider separation and partitioning strategies that would divide the slurry into different fractions. One such fraction would be a nutrients dense fraction that could be more economically transported away from the animal feeding operation, and the other a low nutrient content product that would by applied at high rates around the animal production facility. Here we developed a model that evaluated how the costs of land application changed with the effectiveness of different nutrient partitioning strategies. Utilization of this model allows an estimation of what the farm could spend on the nutrient partitioning system based on potential cost saving in land application costs. The results indicated that there was an economy of scale making the nutrient separation system more cost effective for larger operations. Analysis of two real-world separation systems, a screw press separator and a decanting centrifuge, indicated that in general high separation efficiencies and relatively large farm sizes are required to make currently available systems cost feasible.

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Objective 4. Manure application separation distances and other best management practices

Introduction

Manure land application separation distances, or setbacks, are specified distances from areas that may be vulnerable to water pollution (including surface waters, open tile intake structures, sinkholes, agricultural wellheads, or other conduits to surface waters) where manure cannot be applied. The purpose of the setback is to reduce the potential for potential contaminants (solids, organic matter, nitrogen, phosphorus, microbes, salts, etc.) to reach surface water by increasing the distance between the contributing source area and the potential receiving water. Additionally, the setback distance can potentially improve water quality by acting as filters for water passing over and through the soil toward a water resource, providing an opportunity for solids to settle out, infiltration of runoff water to occur, and contaminants to interact with soil and vegetation and be retained in the field. In all cases these processes are primarily focused on the transport and retention of particulate or

particulate bound nutrients and contaminants, thus the focus of this review will tend to be on how these practices impact the transport of these items.

Federal law for NPDES (National Pollutant Discharge Elimination System) permitted CAFOs (concentrated animal feeding operations) requires the farmer to maintain a setback area of 100 feet from any down-gradient surface waters, open tile intake structures, sinkholes, agricultural well heads, or other conduits to surface waters where manure, litter, and other wastewaters cannot be applied. As a compliance alternative, the CAFO may elect to establish a 35-foot vegetated buffer where manure, litter, and other wastewater are not applied. Although the 35-foot buffer requires less land, it requires the farmer to take some of the field out of row-crop production whereas the 100-foot buffer does not. As an alternative to these requirements, the CAFO rules states "owners or operators may demonstrate to the permitting authority that a setback or vegetated buffer is unnecessary because of site-specific conditions or practices the producer is implementing."

Current state law in Iowa requires that no manure by land applied within 200 feet from a designated area, or in the case of a high-quality water resource within 800 feet. Smaller setbacks can be used if: (1) the manure is land-applied by injection or incorporated on the same date as the manure was land applied, or (2) an area of permanent vegetation cover (including filter strips or riparian buffers) exists for 50 feet surrounding the designated. The vegetative filter area cannot receive manure application. In general, the requirements set forth in Iowa State law are stricter than those required in federal law for permitted CAFO operations with one exception, that being the case where manure is injected or incorporated on the same date as it is applied.

This leads to an important question, what is the science behind these separation distances, i.e., what level of reduction in nutrient concentrations or transport is expected by following current setback distance requirements and do other practices exist that can be expected to provide similar reductions and should be accepted as a site-specific condition or practice? This will be explored in a series of three sections, in section one I will focus specifically on the performance of maintaining manure application setback distance. In section two, I will focus on maintaining a vegetated buffer between the manure application area and the receiving water body. Finally, in section three, I will examine other practices that may be appropriate, with specific attention given to the practice of manure injection or immediate incorporation as this is a practice specifically mentioned in Iowa law, but not mentioned in federal code.

Section 1: Manure application setback – 100 foot no-apply zone

A manure application setback specifies the minimum distance manure can be applied to a defined feature. Current EPA regulations for setback distances is to have a no application zone within 100 feet of the down-gradient surface waters, open tile intake structures, sinkholes, agricultural wellheads, or other conduits to surface waters (200 feet from designated areas via Iowa code). In this option, no manure application is allowed in the setback area, but the setback area can still be used for crop production and currently there are no restrictions on the application of commercial fertilizers that can be utilized in the setback area.

In general, the objective of both 100-foot setback distance or the 35-foot setback with permanent vegetative buffer is to provide a protective strip of land that can serve to filter solids, retain nutrients, and otherwise improve surface water runoff from fields receiving manure. In so doing they reduce nutrient transport to the surface water (or other conduit to water). These practices primarily focus on limiting transport of sediment bound contaminants, but also offer some protection to soluble nutrients, namely ammonia and dissolved reactive phosphorus, by providing regions where these nutrients can potentially interact with soils that have not received recent manure application and offer either sorption mechanisms or an opportunity for infiltration to reduce overall transport.

Relatively few field-studies have specifically evaluated the performance of setbacks, or no manure application zones, had on reducing nutrient transport from fields. However, a recent study by Al-wadaey et al. (2010) was performed with the specific objective of evaluating the effect of setback distance on phosphorus and sediment in runoff from lands receiving manure application. This study was conducted on a 24 ha (59 acre) field protected with underground-outlet terraces located northwest of Lincoln, Nebraska. Field slopes in this area were 4-7%, and the soil was a well-drained silty clay loam. The experiment was run as a replicated block design (3 blocks) with seven different treatments (manure application setbacks of 0, 5, 10, 20, 30, and 40 m, and a no manure check plot). In this experiment, composted feedlot manure was applied to bare, frozen soil in February at an average rate of 74 Mg/ha. Runoff samples were collected from the riser pipe of each treatment from multiple natural rainfall events. Runoff samples were analyzed for sediment (total solids), total phosphorus, dissolved phosphorus, and particulate phosphorus (by difference between total and dissolved phosphorus). An analysis of variance was conducted using Proc Mixed (SAS Institute) to determine the effects of setback treatments on sediment, TP, DP, and PP. ISCO samplers were used on the 0 and 30 m setback plots to monitor flow volumes, allowing a comparison of nutrient transport between these two treatments. These authors found no difference in runoff concentration or runoff volume between the 0 and 30 m setback treatments, but found significantly great sediment transport from the 30 m setback plot. They attributed this finding to the manure providing organic matter, which resulted in formation of water stable aggregates and reduced erosion. Moreover, they found that different setbacks did not significantly affect phosphorus concentrations (total, dissolved, or particulate) among any of the seven treatments.

Another study by Dygert (2011) on setbacks was performed to specifically evaluate the effectiveness of setback recommendations (61-m setback) at mitigating nutrient transport following the application of liquid dairy manure from fields with low slope percent following manure applications on frozen/snow covered ground. This study was conducted near Wooster, Ohio on a field with 2% slope, under no-till management, and with corn residue on the surface. They evaluated two scenarios, a manure application with no setback and a manure application with setback, and for each case compared the runoff concentrations to that with a plot that didn't receive manure. Their treatment design required different plot sizes, making result comparison complicated; however, after proper normalization Dygert's data suggests that leaving a buffer area will significantly reduce ammoniacal nitrogen ($p = 0.09$), total phosphorus ($p = 0.07$), dissolved phosphorus ($p = 0.04$), and potassium ($p = 0.01$) as compared to not leaving a buffer strip.

As only these two studies could be located specific to the performance of setbacks, it was not possible to develop a baseline performance standard from this option against which other potential practices could be evaluated. However, based on details provided in these manuscripts it appears that the hydrology of the runoff event was extremely important to the performance of the setback distance. In the case of Al-wadaey et al. (2010) runoff was measured from rainfall events typically larger than 1-inch, which provided enough flow for water runoff from the manure applied area to reach the tile inlet. In Dyger's study runoff samples were only from snowmelt, and they reported that many of the events weren't of sufficient size for runoff from the manure applied zone to reach the edge of the plot. This made the setbacks appear effective, but larger runoff events would have significantly reduced the setback's effectiveness. These results would seem to indicate that the primary impact of these setbacks have on nutrient transport is prevent manure from reaching the critical area during smaller runoff events, but there effect may be limited during larger events.

A lab-study by McDowell and Sharpley (2002) seems to collaborate this stating, P loss in overland flow is affected by where manure is applied relative to flow-path length, noting specifically that there was a strong relationship between P fractions and flow-path length. However, they also noted that phosphorus lost was to large part driven by soil phosphorus concentrations. Implying that if these critical areas are still receiving phosphorus inputs from mineral fertilizer sources, the setback may not be as effective as we would otherwise anticipated.

Overall, this data suggests to me that these standard setbacks would be most effective in cases of fall-applied manure when runoff events will predominately be from snowmelt and many of the runoff events will be small. If the manure is spring applied these setbacks would have limited impact due to the larger nature of these events causing larger runoff events and the runoff reaching the stream from the land that had received the manure.

Section 2: Manure application setback - 35 foot vegetative buffer

Grass buffers are areas located between the land receiving animal manure and streams, or other conduits to surface waters that reduce the concentration and mass of nutrients and other potential contaminants entering the receiving water. Vegetative buffers, or filter strips, are a practice that has been demonstrated to effectively reduce erosion and P movement (Dillaha et al, 1989). Binham et al. (1980) and Doyle et al. (1977) reported some of the earlier work on vegetative buffers around manure land application areas. In general, they reported reductions of 0-80%, with performance varying based on the ratio of manure land application area to vegetative buffer area and the type of contaminant (soluble versus particulate transport). In general, Binham et al.'s (1980) work with layer hen manure and 35- foot vegetated setbacks indicated that that reductions of 30% should be expected for carbon and chemical oxygen demand, 60% for total Kjeldahl nitrogen, and 80% for total phosphorus.

Since then numerous other studies on buffer strip performance have been conducted with some focusing on land that had received manure and others focusing on buffers around cropland. Although these studies provide considerable information, more recent efforts at understanding buffer strip performance has focused on using modeling to extend the results of the field studies to other situations. The most well know used of these models is the Vegetative Filter Strip Model (VFSMOD) as described in Munoz-Carpena and Parsons (2000). Dosskey et al. (2011) then used this model to evaluate the trapping efficiency for given buffer area ratios with different site conditions (slope, soil texture, and field practices). Based on this they developed a series of curves to provide trapping efficiency for different scenarios, including soil types, slopes, and contaminant types. In the case of the 35-foot buffer on a square 40-acre field, if all runoff drained uniformly to one edge of the field, the buffer-to-field area ratio would be approximately 0.03. Based on the chart they developed, we would anticipate that reductions in total suspended solids would be 10-80%, reductions in total phosphorus would be 5-70%, and reductions in total nitrogen would be 5-60% under Iowa conditions. As expected, these ranges are quite large, but they provide a realistic expectation for filter strips under a large range of conditions.

Section 3: Manure application – Other alternatives to setback distances
(a) Injection

As stated previously, the objective of the two previously discussed practices is to reduce nutrient transport to the surface water (or other conduit to water) primarily by reducing erosion, but also by reducing surface transport of nutrients. It has long been noted that the transport of P from agricultural areas to surface waters is primarily by runoff and erosion, and thus its transport is heavily influenced by surface soil P content and the method, rate, and timing of fertilizer and manure P application (Sharpley et al., 1993). As runoff only interacts with the very top of the soil profile, injection or immediate incorporation have both been proposed as best management practices for reducing transport of manure nutrients as it moves the manure to a zone in the soil where it will have less interaction with runoff water and therefore be less prone to transport and loss.

A recent study by Gilley et al. (2013) evaluated several different manure land application methods (broadcast, broadcast with disk incorporation, injection) for three sources of swine manures (grower pigs, finisher pigs, and sows). This study was performed at the plot-scale in Nebraska and used simulated rainfall, but offers a direct comparison of how different application methods impacted nutrient transport in surface runoff. They found that injection decreased dissolved phosphorus transport by 60%, particulate phosphorus transport by 40%, total phosphorus transport by 46%, ammonia transport by 84%, and total nitrogen transport by 20%. In general, these

reductions are well within the range that we would expect to be achieved with the 35-foot vegetative buffer. Gilley et al. (2013) also compared the use of disk incorporation to surface broadcast, in this case the results indicated that incorporation decreased dissolved phosphorus by 45% but increased total phosphorus by transport by 20%. Similar results were seen for nitrogen as incorporation reduced ammoniacal nitrogen transport by 50% but increased total nitrogen transport by 24%. These results are as expected, injection placed the manure below the soil surface while minimizing soil disturbance, this resulted in a situation where the soluble contaminants were not in contact with the surface runoff and as a result, their transport was minimized. This was done while causing minimal soil disturbance, soil transport of sediment bound contaminants was also minimized. In the case of incorporation, the transport of soluble contaminants was reduced by encouraging their contact with soil particles and working it below the soil surface, but the tillage resulted in greater potential for transport of sediment bound contaminants.

A 1979 study by Ross et al. quantified the quality of runoff from land receiving either surface application or injection of liquid dairy manure. In this study Ross et al. (1979) injected manure into both sod and a tilled loam soil at depths of 15.3 and 30.5 cm and a surface application onto both the sod and tilled soil. In performing this study they evaluated three factors, these were: (1) the effect of injection versus surface application, (2) the effect of injection depth (15.3 versus 30.5 cm), and (3) the impact of surface conation (vegetated versus tilled). In their study, they found that injection reduced runoff concentrations to levels typical of those of plots not receiving manure application. This represents a substantial reduction as compared to surface application, for example COD (chemical oxygen demand) was 17x lower in the injection plots than in the surface applied plots, with the depth of injection having little effect in this study. This again provides strong evidence that injection provides a high level of reduction in nutrient transport.

The final injection study we will look at is by Pote et al. (2011). This study is unique in that is was injection of a solid manure (unfortunately the unit is not yet commercially available). In their research, they found that subsurface injection reduced concentrations of nitrogen and phosphorus in runoff water by more than 90% as compared to surface application. In a paired watershed part of the study they found that total phosphorus losses were 55% less in the watershed that received subsurface litter application than the one that received surface litter application. In the first several runoff events after litter application dissolved reactive and total phosphorus concentrations in runoff water were typically reduced by more than 80% by utilizing injection application.

Overall, these studies give a clear and consistent picture that injection application will provide similar or better reduction in nutrient concentrations and transport as to those that would be obtained using the 35-foot vegetative buffer between manure application areas and surface waters (or conduits to surface waters).

(b) Incorporation

A 2008 study by Allen and Mallarino utilized swine manure and sites located within Iowa to evaluate how application rate, incorporation, and timing of rainfall impacted phosphorus losses with surface runoff. Their results indicated that incorporating the manure with tillage resulted in significantly lower runoff P concentrations and loads. This result is generally consistent with existing research as incorporation places the manure P below the zone of interaction between the soil and incoming rainfall and runoff, reducing dissolved reactive phosphorus (Wither et al., 2001; Tabbaraa, 2003; Haq et al., 2003; Daverede et al., 2004).

Another recent study (Pote et al., 2003) focused on the water-quality effects of incorporating poultry litter, in this case into grassland soils. In this study, they had four treatments, a control (no litter), a surface applied litter, a surface-applied litter to aerated soil, and a surface applied followed by knife to incorporation to minimized disturbance of the soil structure by using a knife tool for injection. This work was performed on field plots with 8-10% slopes, silt loam soil, and well-established grass forage. They found that in all cases adding litter increased infiltration, but results weren't significant. In this case, incorporation of the litter reduced dissolved

organic carbon transport by 58%, total dissolved solids transport by 36%, and total suspended solids transport by 57%. In this case, nitrogen and phosphorus transport was also successfully reduced by 44% for nitrate-nitrogen, 83% for ammoniacal-nitrogen, and 81% for total Kjeldahl nitrogen and by 89% and 85% for dissolved reactive phosphorus and total phosphorus respectively. Surface application also reduced transport of these items, but to a much lesser extent, only resulting in a 11% reduction in dissolved carbon transport, a 36% reduction in dissolved solids, and a 57% reduction in suspended solids. Nitrogen and phosphorus transport reductions were 6% (nitrate-nitrogen), 25% (ammoniacal-nitrogen), 28% (total Kjeldahl nitrogen), 13% (dissolved reactive phosphorus), and 9% for total phosphorus. These results suggest that low disturbance incorporation into perennial vegetation can be very effective at reducing nutrient transport and is roughly equivalent to 35-foot filter strips, but the performance of aeration followed by surface application isn't quite equivalent.

Again, these studies indicate that incorporation is a valuable technique for reducing the transport of water-soluble nutrients and contaminants as their interaction with the soil reduces their transport. However, results on sediment bound nutrients and contaminants are less clear, given that the tillage for incorporation reduces surface cover. In some cases, this can lead to increased erosion, and as a result, an increase in the transport of sediment bound cartilages.

Conclusions

At this time, very few studies on the performance of manure application setback distances are available and none have directly compared setbacks to other application practices such as injection or incorporation within 24-hours. Thus, I recommend that future studies comparing these practices with similar soil, weather, and manure characteristics be performed. Preliminary evidence available in the literature would seem to indicate that both injection and incorporation within 24-hours would provide similar or better levels of reduction in nutrient transport from manure application areas as the current setback requirements, statement and proof of such is difficult.

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IX.   Discussion: Explain your research results and include a summary of the results that is of immediate or future benefit to pork producers.

Our first objective was to compare manure production to crop nutrient need. These results indicated that Iowa has sufficient capacity to utilize all the manure produced. This result is of value as often manure receives heavy scrutiny and blame for water quality. Our result indicates that in Iowa, and by extension, the Midwest, manure only provides a part of the required nutrients and is therefore usually valued as a potential fertilizer source.

Our second objective was to evaluate the economic benefit of annual manure sampling and testing. This is a practice that when utilized correctly is known to improve manure nutrient utilization. However, data indicates that only about 20-30% of farms test their manure's nutrient content annual for nutrient planning purposes. Our results indicated that annual manure sample could provide about $1600 of value annually to a 1200-head swine finishing barn. This provides strong evidence that manure sampling is not only a best management practice for environmental protection, but also provides and economic benefit to the farmer.

Our third objective was to determine what performance and cost characteristics would be required to make nutrient separation technologies achievable on animal production farms. Numerous technologies including solids separation, struvite formation and capture, ammonia volatilization and capture, and treatment with acid salts have been proposed as ways of treating animal manures to separate nutrients. However, to date no work had been performed to understand the performance and cost requirements these practices would need to meet to be economically advantageous on Midwestern U.S. farms. Our work here can be used to help refine constraints on these systems so that appropriate designs can be selected. Additionally, the economic tool we developed will aid farmers in determining how and if these systems will bene it their farm.

Finally, we also evaluated the impact of manure setbacks on nutrient transport from manure application areas and compared this to other management practices such as injection or incorporation within 24-hours. No direct comparisons of these practices were available, making conclusive statements about equivalent performance difficult. However, the evidence would seem to indicate that injection or incorporation of manure would meet or exceed the level of control offered by these setback distances in most situations.