Cover crop, manure application timing, nitrification inhibitors, and biochar impact nitrogen loss in Midwestern soils

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

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ABSTRACT

Manures are known to be useful fertilizers, but challenges associated with equipment availability, timeliness of field activities, and storage management can make the utilization of manure as a fertilizer more challenging than other options. As farmers face greater scrutiny about their production practices and their impact on water quality, the need for tools in nitrogen management increases. These include, but are not limited to: cover crops, nitrification inhibitors, and biochar used with animal manures. These three topics will be investigated in lab settings and encompass this thesis. Cover crops have the ability to protect the soil from erosion, provide organic matter through biomass and assist in nutrient retention. We investigated the most optimal time to apply liquid swine manure with a cover crop, as to provide best practice techniques for farmers. Nitrification inhibitors are applied with a fertilizer and work to disrupt the nitrogen cycle, improving nutrient uptake for the crop. A meta-analysis was completed to determine the effectiveness of these inhibitors in a variety of settings in the Midwestern United States. Biochar works as a soil amendment, provides water and nutrient retention, and adds carbon to the soil. We are able to determine that cover crops may be used with swine manure for NO₃-N retention, if cover crop is given adequate time to emerge and establish itself. Nitrification inhibitors are a great addition to fertilizers due to their ability to retain nitrogen, offering corn yield benefits. Lastly, biochar is understood to be a beneficial addition to liquid swine manure to provide nutrient retention in soils. The objective of this thesis was to understand better how each of these tools can assist in nitrogen management in agriculture, in order to provide recommendations for those in the agriculture industry.
CHAPTER ONE: GENERAL INTRODUCTION

Agriculture has long been considered one of the leading and largest industries in the United States. In Iowa, agriculture generated “almost $29 billion in crop and livestock sales” (United States Department of Agriculture – National Agriculture Statistics Service Information - Table 1, 2017). There are more than 30.6 million acres dedicated to farmland, indicating that there are thousands of farmers whose livelihood is in agriculture. (United States Department of Agriculture – National Agriculture Statistics Service Information - Table 1, 2017). The efficiency and profitability of their cropping systems is crucial. These are the main concerns in crop production, which are very real to these farmers. Primarily, nutrient and yield loss cause efficiency and profit loss, which has created a need to investigate methods to mitigate the risks.

Some practices in agriculture can contribute to environmental issues such as erosion, water quality, and decreased soil organic matter (van der Werf and Petit, 2001). These issues are of concern among environmentalists, agronomists, and policy makers. Heavily used cropping systems can cause detriments to soil quality (Vincent-Caboud et al., 2019). Specifically, a large concern to policy makers and farmers is nutrient loss, as it creates both environmental and efficiency issues. As a result, farmers have faced pressure to incorporate practices that are deemed more sustainable into their cropping systems (Food and Agriculture Organization, 2003). A key player in this sustainable revolution is the Iowa Nutrient Reduction Strategy, which aims to reduce nutrient loss by incentivizing the use of certain practices. Some of these practices include the planting of cover crops, appropriate use of animal manures, nitrification inhibitors, and biochar. These programs have depended on farmer cooperation and adoption of these practices to reduce nutrient loss (Iowa Nutrient Research and Education Council, 2017).
Sustainable intensification is the incorporation of work that promote increased productivity, while saving external resources. In other words, “doing more with less” (Food and Agricultural Organization of the United Nations, 2012). It is crucial that agriculture is “able to continue over a period of time…[by] causing little or no damage to the environment and therefore able to continue for a long time” (Cambridge Dictionary, n.d.). Sustainable agriculture has a few major goals, of which to maintain “environmental health, economic profitability, and social and economic equity” (National Sustainable Agriculture Coalition, n.d.). It is crucial that agriculture systems honor these goals to ensure the continuation of agriculture systems and the industry. Sustainability should encompass the health of system both today, and in the future. Examples of sustainable agriculture practices that are highlighted in this dissertation include applying animal manure as a recyclable means to fertilization, planting cover crops, using inhibitors to slow the nitrification process, and the application of biochar for nutrient loss reduction.

**Objectives**

The goal of this dissertation is to investigate the relationship that a variety of sustainable practices have with one another. These studies will provide recommendations for sustainable practices that farmers and agronomists can incorporate into their cropping systems confidently. There are three objectives of this research focus:

1. The relationship between manure application timing and the use of cover crops will be examined by NO$_3$-N loss from soil columns.

2. A meta-analysis to understand how nitrification inhibitors may be used with fertilizer in order to reduce nitrogen loss and aiding an increase in corn yield.
3. Evaluate the impact that biochar and swine manure have on nitrogen loss from soil columns.

**Thesis Organization**

The research presented is organized into three papers, each specifically addressing an objective above. The first two papers, “Evaluation of Cover Crop and Manure Application Timing on NO$_3$-N Loss in Midwestern Soils” and “A Meta-Analysis on the Impact of Nitrification Inhibitor and Fertilizer Application on Corn Yield in the Midwest”, were presented at the 2019 ASABE Annual Meeting in Boston, MA. The final paper is titled “Effect of Biochar and Animal Manure on NO$_3$-N Loss from Soil.”

**Literature Review**

Proper soil health is necessary for crop production, leading to the incorporation of systems to reduce agricultural impact. It is important to conduct research in these areas to gather more data in order to build confidence. We intend to provide recommendations for farmers, agronomists, and horticulturists. It is crucial to understand the nitrogen cycle in order to understand the implications of this research.

Nitrogen is the “fourth most abundant element in cellular biomass” and considered a limiting nutrient (Stein and Klotz, 2016). This means that without adequate amounts of nitrogen, plant growth may be stunted. There are three main processes within the nitrogen cycle: N$_2$ fixation, nitrification, and denitrification, and the disruption of this cycle is of interest to those in the cropping industry. Nitrogen, N$_2$, exists in the atmosphere and is reduced to NH$_4^+$, ammonia. Ammonia is oxidized by *Nitrosomonas sp.* into nitrite, which is then oxidized into nitrates by
Nitrobacter (The Encyclopædia Britannica, 2012). Plants can use both ammonia and nitrates, but the conversion of ammonia to nitrite and then nitrate is fairly quick, leaving nitrate to be used primarily by plants. In addition, because NH₄⁺ is a positively charged ion, it remains in the negatively charged soil. Nitrate leaches or denitrifies from the soil quite easily due to the repellant nature of its negative charge (Allred, 2007; Iowa State University Extension and Outreach, 2019).

Nitrate is a highly mobile nutrient, causing water contamination issues, which results in potential harm to organisms and ecosystems. This is a fairly quick process, which creates the need for efficient application and use of nitrogen. Although nitrate is a usable form of nitrogen for plants, it is highly mobile, meaning it can be denitrified into groundwater. This can create contamination issues for aquatic ecosystems. This nutrient loss also creates a loss of resources and efficiency in the application of fertilizer. This efficiency loss concerns farmers who are aiming to fertilize their land. Farmers have resorted to various methods of fertilization to increase efficiency, such as animal manures.

Animal manures provide an economically friendly means to add nitrogen, phosphorous, and potassium to the soil. Sources may include swine, cattle, or poultry, and applied via injection or broadcast on the soil. This form of fertilization has recently been favored, as it gives use to animal waste, and decreases the dependence on synthetic fertilizers may decrease (Regan and Andersen, 2014). This reduction in synthetic fertilizer use may be more economically friendly for farmers and play a role in more sustainable system. However, animal manures may create environmental concerns due to the denitrification that can occur, leaching nitrates into groundwater. This creates the need for practices that increase nitrogen application efficiency, lowering potential production costs and environmental contamination.
Animal manures improve soil structure and add nitrogen, phosphorous, and potassium, making it a key player in building sustainable agriculture systems (Andersen, 2013). Manures may be injected or applied on top of the soil, depending on the season. Application timing is to be considered in fertilization. Animal manures are typically applied during fall season after soil temperatures are below 50 degrees Fahrenheit, or during spring or summer (University of Minnesota Extension, 2018).

However, there is more to be considered than just soil temperature. If manure is not applied at an optimal time, nutrients may be lost. Application is key to nutrient use efficiency, which has formed the question to be answered in this thesis. If manure is applied regardless, what are steps that can be taken to mitigate the risk of nutrient loss? Cover crops may be planted ahead of manure application in order to capture nitrogen, thus reducing overall loss. This is a question we intend to address in this thesis.

Cover crops have been used to protect soil from erosion and the loss of nutrients (Dabney et al., 1998). The authors performed a review on cover crop impact on water flow in agricultural fields. They concluded that “perennial cover crops offer the potential for altering the porosity of subsurface soil horizons”, which helps to reduce future runoff rates (Dabney et al., 1998). It is understood that cover crops produce biomass, which transpires more water. This works to dry the soil, allowing more rainfall to infiltrate into the soil. Cover crops work to intercept “the kinetic energy of rainfall and by reducing the amount and velocity of runoff” (Dabney et al, 2001). In addition, cover crops add competition for light and water, thus contributing to weed suppression (Vincent-Caboud et al., 2019).

In addition, plants can secure nitrogen in the biomass of the cover crop, reducing the potential for nutrient loss through water leachate (Miguez and Bollero, 2005; Hashemi, 2013).
Miguez and Bollero completed a meta-analysis evaluating the use of winter cover crop on corn yield and found that the use of cover crop can be highly variable due to the type of cover crop or use of nitrogen fertilizer. This increases the need to complete more studies on the use of cover crop and fertilizer.

Cover crops can reduce the amount of soil erosion, NO$_3$-N loss, and increase the amount of nitrogen contributed for the subsequent crop (Holderbaum et al., 1990). The evaluation of fall planted cover crops performance over winter was completed and was determined to have a small contribution of nitrogen to following crop seasons. While the contribution was not large in all scenarios, it is still believed to have a beneficial impact. This adds to the ideology that cover crops can help to enhance the environmental performance of crop systems, causing direct influence on crop production and quality (Martinez-Feria et al., 2016).

Another means of reducing nutrient loss is the use of nitrification inhibitors, which are used with fertilizers to help control the rate of nitrification within soils. Because nitrogen is a fairly mobile nutrient, it is of large concern regarding nutrient loss and subsequent contamination issues. Farmers rely on fertilizers to ensure the transport of nutrients to the soil and for crop production. However, there is still an inevitable loss of nitrogen, especially when fertilizer is applied in excess, which has led to the development and implementation of solutions to reduce the risk.

Nitrification inhibitors are of large interest because they can be used to manage nitrogen within soils and mitigate nutrient loss (Sassman, 2014). One of the more common nitrification inhibitors is nitrapyrin, which is typically labeled as N-Serve, produced by Dow AgroSciences. Specifically, it inhibits *Nitrosomonas sp.*, a bacterium, which allows for the stabilization of fertilizers in the soil, increasing the potential N availability for plant growth (Sassman, 2014;
These inhibitors are incorporated into fertilizer application, such as anhydrous ammonia or animal manure.

The effectiveness of nitrification inhibitors on the nitrogen cycle has been studied, specifically its impact on maize grain yield and reduction of nitrogen losses (Warren et al., 1980). These benefits are explained in many of the studies highlighted in the third chapter, which will be examined in more depth as part of a meta-analysis. Nitrogen efficiency is maintained with increased corn yield with nitrapyrin application (McCormick et al., 1984). It is crucial that nitrogen efficiency is maintained or improved, but not at the cost of corn yield.

The intent of the meta-analysis is to determine the overall effectiveness of nitrification inhibitors in the Midwestern United States. Trends among nitrification inhibitor application rate, nitrogen application rate, location, nitrogen source and method of application will be established to provide recommendations for the use of inhibitors.

The reduction of nutrient waste, being the development of composting and pyrolysis, is of great recent interest. Biochar is a product of pyrolysis and is carbon rich (Oldfield et al., 2018). There is great potential for carbon sequestration, as biochar contains a stable form of carbon. A stable form of carbon has the ability to “offset potential negative effects of the composting system” (Oldfield, 2018). Biochar is potentially environmentally beneficial; in that it recycles carbon and phosphorous. There is much research to be done on the effects of biochar, to fully understand the benefits and consequences of using it in soil systems. The basis of the research done in this dissertation centers on the relationship that biochar and manure can have on nitrogen loss from soils.

A study performed by Thomas Oldfield and others highlighted the use of biochar as a means to recover nutrients and sequester carbon (Oldfield et al., 2018). They found that biochar
offered benefits in carbon recovery capacity, resulting in lower nutrient loss and higher crop yield (2018). Biochar is an efficient way to repurpose agricultural waste, especially if it has the capability to improve cropping systems. More studies are to be completed relating to biochar and soil systems, in order to give farmers confidence to incorporate biochar into their crop systems.

In another study, biochar impact on nutrient leaching in Midwestern soil was investigated. Biochar was applied in varying amounts and leached water samples showed a decrease in nitrogen, phosphorous, magnesium, and silicon (Laird et al., 2010). Despite the fact that biochar added “substantial amounts of these nutrients to the columns”, the amount of nitrogen loss was reduced by 11%, which builds the case that biochar can be a beneficial addition to soil systems (Laird et al., 2010). These results support the idea that biochar may be incorporated into a sustainable agricultural system.

Sustainability encompasses many ideas and practices, which will be discussed in this dissertation. The discussion of sustainable agriculture will continue to grow, with a goal of forming recommendations for farmers and agronomists. It is crucial to continue the conversation, in order to reduce uncertainty surrounding the use of cover crops, animal manures, nitrification inhibitors, and biochar. Research in sustainable agriculture has the potential to make a great impact on efficiency within cropping systems.
References


CHAPTER 2: EVALUATION OF COVER CROP AND MANURE APPLICATION TIMING ON NITROGEN LOSS IN MIDWESTERN SOILS

Abstract

Midwestern farmers commonly apply manure as fertilizer to add nitrogen, phosphorus, and potassium to the soil. The addition of cover crop to agricultural systems has been stated to provide organic matter to soil, erosion control, and reduce nitrogen loss from the soil. Each of these benefits contribute to sustainable agriculture systems. One of the major concerns among farmers is the loss of nutrients, specifically nitrate as nitrogen. This can not only create the potential for lost efficiency, but also one of environmental quality. If nitrates leach into groundwater, it can create contamination issues within water systems. Through the combination of cover crop and the optimal timing of manure application, the amount of nitrate lost as leachate may be reduced. The objective of this experiment was to find the optimal time to apply liquid manure when combined with a cereal rye cover crop. We compared the use of cover crop with various manure application timings (immediate, two, and four weeks after cover crop emergence), by measuring the nitrate concentration in leached water samples on a weekly basis. This study aimed to provide guidance on how different manure application timing and the use of a cover crop can mitigate NO$_3$-N loss in soil columns. Our results have suggested using a cover crop in soil systems can reduce the amount of NO$_3$-N loss. If using liquid swine manure, it is suggested from this study to apply four weeks after cover crop emergence. It can be inferred that cover crops need time to emergence in order to mitigate nutrient loss from manure applied soils.
Introduction

Sustainability has become a focus in agriculture, as it encompasses the long-term efficiency of a system. Various practices in agriculture can contribute to environmental issues such as erosion, water quality, and decreased soil organic matter (van der Werf and Petit, 2001), leading to the research, development, and implementation of solutions to improve sustainability and mitigate environmental risks. It is important to provide tools and methods for farmers to reduce their potential impact on the environment (Robertson and Vitousek, 2009). One of the main environmental concerns is water quality, due to the inability to retain the nitrogen in the soil, causing contamination (Robertson and Vitousek, 2009).

When fertilizers are applied to the soil, numerous nutrients are added, such as nitrogen, phosphorus, and potassium. The element of interest in this chapter is nitrogen. Applied ammonium (NH$_4^+$) undergoes conversion to nitrite (NO$_2^-$), and then to nitrate (NO$_3^-$). Nitrate is a highly mobile compound and has a greater likelihood to leach away from cropping systems, which creates a reduction in soil and water quality. This rapid conversion makes nitrogen loss a great concern from both a crop efficiency and groundwater contamination standpoint.

Farmers have demonstrated an interest in cover crops, as it was the most requested topic over the past two years at the Iowa Manure Applicator Certification Training meetings and Iowa Learning Farms field days. They are interested in understanding how these practices can be implemented on their farms to improve soil quality and control nitrogen movement in the soil. Cover crops have demonstrated nitrogen loss benefits, but only about 2-3% of cropland has been dedicated specifically in Iowa (Agriculture Policy Review, Iowa State University). The NRCS has called for millions of acres to be planted to cover crops, but confidence in cover crops is still
wavering. The variability in cover crop growth may be to blame for the low rates of implementation (Muñoz et al., 2014).

Cover crops can have several positive impacts on soil systems, such as decreased runoff potential, improved soil structure, and reduction of nutrient loss. Cover crops have the ability to dry the soil and allow higher amounts of water to infiltrate into the soil, decreasing the amount of runoff and erosion (Dabney et al., 1998). Cover crops also assist in the reduction in subsurface drainage, acting to reduce the amount of nitrate leached into groundwater (Qi et al., 2011). In addition, cover crops have demonstrated the ability to improve soil structure and increase biomass production (Pantoja, 2013).

When cover crops are planted, nitrate-nitrogen can be scavenged, and the loss of nitrate to the environment decreases (Jewett and Thelen, 2005; Hashemi et al., 2013). Another group of researchers found that cover crop reduced the amount of available nitrogen after corn growing season, which is when nitrogen is highly prone to loss (Eigenberg et al., 2002). There is potential to increase the amount of nitrogen contributed to the subsequent crop, which was calculated by comparing corn total nitrogen uptake with no cover crop from the corn total nitrogen uptake on plots with a previously grown cover crop (Holderbaum et al., 1990). The increase in nutrient availability can help to increase corn yields, rather than creating a yield penalty (Miquez and Bollero, 2005; Muñoz et al., 2014; Snapp and Surapur, 2018).

Cover crops can be planted after a main crop, providing soil with higher organic matter and nitrogen mineralization relative to those without a cover crop (Moore, E.B. et al., 2014). Cover crops have the ability to fix nitrogen through a symbiotic relationship with bacteria (Edwards and Burney, 2005). Specifically, cover crops can scavenge nitrate and convert it to a more immobile organic nitrogen, making it more plant available (Cooper et al., 2017; O’Reilly et
Cover crops increase soil organic matter and increase carbon inputs (Dabney et al., 2001). Cover crops have the potential to maintain nutrient levels in soils, which is crucial for crop production, making it a potentially efficient addition to agricultural systems.

The interest in animal manure is likely due to their potential to improve soil structure and add plant available nitrogen, phosphorus, and potassium, contributing to increased crop yields (Barnhart, 2001, McCormick et al., 1984; Sawyer, 2001). The application of swine manure has the ability to improve soil fertility, creating a better environment for crop growth (Andong et al., 2019). Manure is of high interest in Iowa, as there is a large amount produced each year. Iowa is a leader in swine production, thus creating a great amount of manure available (United States Department of Agriculture, 2019).

The recycled nature of manure makes it a key player in building sustainable agriculture systems. Manure is considered an environmentally and economically friendly means of fertilization, decreasing the dependence on synthetic fertilizers (Regan and Andersen, 2014). The recycling of manure by applying it by land closes the nitrogen cycle, improving sustainability (Regan and Andersen, 2014; Alam and Chong, 2010). In addition, the use of manure as fertilizer can be more economically friendly for some farmers, especially if they already have it from livestock production. Animal manures are considered an excellent resource for crop nutrients, building the confidence in using it for crop rotations (Sawyer, 2007). The manure application window may have some constraints, due to weather or other logistics.

If farmers want to use a cover crop, it is important to provide recommendations as to when to apply manure with respect its constraints. We believe that there is an optimal time to apply swine manure after the emergence of cover crop. With this information, farmers will have a better understanding as to how to incorporate both cover crops and swine manure.
Objective

Our objective is to provide recommendations for optimal manure application timing, with the use of a cover crop, to reduce nitrogen loss from the soil. In our study, various manure applications were made, at three different times after cover crop planting. We believe there is an optimal time to plant cover crops and apply manure, to aid in the reduction of nitrogen lost through water leachate. An ideal combination will allow the cover crops to capture the nutrients in the manure, leading to less nitrogen loss. The reduction in nitrogen loss can mitigate risks of contamination. This research is valuable to current farmers, who are facing scrutiny to reduce their environmental impact, without taking a hit in crop yield. We intend to offer recommendations not only for the use of a cover crop but an optimal planting time when used with animal manure treatment.

Methodology

The experiment was performed on Iowa State University’s campus, in the Manure Management Laboratory in Elings Hall. A structure made of wood held 18 PVC pipes with a 15.25 cm diameter. Each were filled to 5 cm with sand and gravel rock to prevent soil fallout, followed by approximately 2000g of soil. There were two types of soils used for this study. These soils were taken from the Iowa State Agricultural Engineering and Agronomy farm located in Boone, Iowa. Both were collected in the spring from a Clarion series soil texture and in a plot that had been soybean the previous year and on which rye cover crop had been grown. The bulk densities of soil A and B were approximately 1.04 and 1.34 g/cm³, respectively.
There were six treatments among the 36 columns, including different variations of two factors: cereal rye cover crop and liquid swine manure. The treatments included soil only, cover crop only, and swine manure only. In addition, different manure application timings were used with a cover crop: immediately, two-week delayed, and four-week delayed, after cover crop emergence. At standard room temperature, cereal rye cover crops were planted into the designated columns at 75lb/acre, with a goal of 10 cover crop emerging plants in each column to provide sufficient cover. 30 mL of liquid manure was pipette applied to designated columns with a targeted rate of 6000mg/1L, with an assumed nitrogen availability of 90-100% (Sawyer, J.E., and A.P. Mallarino, 2008).

| Table 1: Liquid Swine Manure Properties |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| TS   | VS     | TKN    | NH4   | NTP    | PO4-P   |
| %    | %      | mg/l   | mg/L  | mg/L   | mg/L    |
| 7.6  | 6.3    | 6700   | 5800  | 2700   | 1400    |

It is important to note that after the initial application of manure, the cover crops that had emerged were dry, depleted and fragile. The following manure applications were completed at the same rate but diluted with 300 mL deionized water to prevent this from occurring again. This may have some impact on results, as the cover crops from the immediate manure timing may have been of a lower-quality state than those of the two- and four-week delayed application.

Initially, the columns received 150ml water and were allowed to fully drain into a glass bottle. When the columns had finished leaching, the mass of water in each glass bottle was weighed.
and recorded. A subsample of 50mL was collected into corresponding labeled small plastic bottles. For all subsequent leaching dates, 250mL of water was poured through each column, allowed to drain, and subsamples were collected.

After all subsamples were collected, 5ml of 2M monoammonium phosphate (NH₄H₂PO₄) and 1 mL of nitrate stabilizing solution was added to each bottle. Calibration solutions of 10, 100 and 1000 mg-N/L were prepared and used to create calibration curves. These curves were used to determine nitrogen concentration, as it is inversely proportional to the voltage reading from the Oakton Ion 700 benchtop meter (EPA, 2007). With this calibration curve, the x is the log₁₀ value of N concentration and y is the Oakton voltage reading. Once N concentration (mg-N/L) is calculated, it is multiplied by mass leachate (mg/L). With 1 liter of water being 1kg, units cancel to give total NO₃-N leached in mg.

Mass amount of NO₃-N per volume was converted to kilograms per hectare. This conversion was to demonstrate the mass of nitrate leached within a specific area, known as specific density. In addition, this unit gives us the ability to normalize for the concentrations given in varying amounts of water leached through each column. All data was analyzed within JMP to determine least square means, standard error means, and total cumulative loss per column. To determine the effect of cover crops and various manure application times, analysis of variance (ANOVA) was used to test treatment effects. A two-factor analysis was completed, with soil type as a random effect factor and each treatment as a fixed factor.

**Results and Discussion**

All data was evaluated by weekly and cumulative NO₃-N loss among the six columns per treatment. Illustrated in Figure 1, the use of a cover crops reduced the total amount of nitrate lost
from each soil column, 36.9 compared to 28.9 kg/ha within soil only, a 22% decrease, on average. The application of manure showed an increase in nitrate loss, 36.9 compared to 48.8 kg/ha, per column, on average.

![Figure 1: Soil Only, Soil + CC, and Soil + Manure Cumulative NO₃-N Loss Over Days; Shared letters show no significant difference, Letter order from top to bottom: Soil + CC, Soil Only, Soil + Manure](image)

In terms of manure application timing, a delay in application timing when using a cover crop demonstrated the potential to reduce nitrate loss from the soil (Figure 2). When animal manure was applied four weeks post cover crop emergence, 51.2 NO₃-N kg/ha was lost cumulatively per column, on average, which is less than both immediate and two-week delayed applications. This was compared with immediate and two-week delayed application NO₃-N losses of 62.5 kg/ha and 62.9 kg/ha, respectively. While the cumulative loss was nearly the same between immediate and two-week delayed application, the week by week NO₃-N loss in Figure 3
shows a greater loss from an immediate application, though not statistically. Regardless, the expected trend is seen when evaluated over time.

It was hypothesized that cover crops would reduce NO$_3$-N loss from soils when used with manure application. NO$_3$-N losses from all designated columns when manure is applied with a cover crop are shown at all time points. At each of these time points, the delay in manure application after cover crop emergence shows there is a reduction in the amount of nitrogen loss. The above graph demonstrates the NO$_3$-N loss over weeks, by treatment. At the 14-day mark, the two-week delayed manure application was completed. At the 28-day mark, the four-week delayed manure application was completed.

There were no significant differences between the first two applications, immediate and two-week delay, for the first few weeks they were leached. When the third application timing
was performed at day 28, there was a significant difference in NO\(_3\)-N loss, compared to the two previous applications. At this time point, the columns with cover crops and an immediate manure application, two-week delay, and four-week delayed had lost 29.5 kg/ha, 22.6 kg/ha, and 16.574 kg/ha NO\(_3\)-N, respectively and cumulatively.

The intent was to evaluate cumulative NO\(_3\)-N loss, which was not significantly different between the three manure application timings. The four-week delayed manure application had the least total amount of NO\(_3\)-N lost from the soil, which could have been expected. It is likely that the soil needed some sort of preparation by the cover crop for manure application. An older and more developed cover crop can be more successful in nutrient retention, supporting the results that four-week delayed manure application reduced NO\(_3\)-N loss. Another explanation may be that this manure was not applied until four weeks after leaching had begun, so there was no nitrogen applied to the soil for the first four weeks of the experiment, which may partly explain the reduced NO\(_3\)-N loss.

**Conclusion**

Cover crops work to retain nitrogen from the soil and prevent loss through leachate (Christianson *et al.*, 2017). We want to assist in building confidence for the use of cover crops for nitrogen management. It appears the cereal rye cover crops in our study successfully retained nitrogen, as demonstrated in the addition of cover crop. Our purpose was to investigate the relationship between cover crop planting and manure application, and their combined effect on NO\(_3\)-N loss. It is important to understand this interaction, because of the common usage of manure as a fertilizer in cropping systems and the need to build confidence in cover crop usage. Our study indicates the least amount of NO\(_3\)-N lost cumulatively was in the columns where manure was applied four weeks post cover crop emergence. It could be inferred the cover crop
must be established to retain nitrogen but cannot be determined. Further investigation is necessary.

The results indicate the inclusion of a cover crop has the potential to reduce the overall amount of NO$_3$-N loss within the soil. In addition, the results suggest there is a complementary relationship between cover crop and manure application, specifically at a time that allows for adequate cover crop growth. It can be concluded the greatest average cumulative kg/ha NO$_3$-N loss among both types of soil was from the columns with cover crop and two-week delayed manure application, followed by cover crop and immediate application. If a farmer chooses to use both a cover crop and manure application, it is recommended to apply manure a few weeks after the cover crop has emerged. This is due to the idea a cover crop must be more fully grown for greater nitrogen uptake and immobilization, allowing for more efficient nitrogen use.
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Pantoja, Jose L. (2013). Effect of Corn Stover Harvest and Winter Rye Cover Crop on Corn Nitrogen Fertilization, Graduate Theses and Dissertations.


CHAPTER THREE: A META-ANALYSIS ON THE IMPACT OF NITRIFICATION INHIBITOR AND MANURE APPLICATION ON CORN YIELD IN THE MIDWESTERN US

Abstract

Manures are known to be useful fertilizers, but challenges associated with equipment availability, timeliness of field activities, and storage management can make the utilization of manure as a fertilizer more challenging than other options. As farmers face greater scrutiny about their production practices and their impact on water quality, the need increases for sustainable practices that improve nitrogen management. Proper manure application timing and use of additives, such as nitrification inhibitors have received recent attention. Nitrification inhibitors have the ability to hold nitrogen from fall manure applications until crops can use it in the spring. Our work here will review and perform a meta-analysis of existing literature to assess the impact nitrification inhibitors have on corn yield in the subsequent growing season when used with fall manure application. It is believed nitrification inhibitors will not only assist in an increase in corn yield but also reduce the amount of nitrogen lost from the soil. Our goal is to provide recommendations for those working in the agriculture industry to better capture the nitrogen value of the manure. This will help farmers define the constraints on the fall manure application window so equipment needs can be better identified. We can conclude the addition of nitrification inhibitors can assist in providing nitrogen management and increase corn yield.
Introduction

Farmers are faced with a number of challenges, including demands to increase production in order to meet the needs of a growing population. As of late, farmers have received criticism about their planting and operation practices, and their impact on land and water quality. The agricultural industry currently covers over half of the land in the United States (United States Department of Agriculture, Economic Research Service, 2018). This grand land use suggests the need for improvements that mediate the risk that come with crop production, without hindering production.

One large concern of farmers is nutrient loss of manure applied in cropping systems. Nitrogen moves within the soil and undergoes reactions that form new compounds. Called biological fixation, nitrogen is converted to ammonium ($\text{NH}_4^+$). Ammonium is oxidized to nitrite ($\text{NO}_2^-$) by *Nitrosomonas* and then oxidized further to nitrates by *Nitrobacter* ($\text{NO}_2^-$ and $\text{NO}_3^-$). The nitrogen cycle is quite fast, and results in the quick uptake, but also, loss of nitrogen. Nitrogen is vital for plant production, so farmers have resorted to fertilizers to ensure proper nutrient application (Wu, Chenkai, 2016). Manures have been selected as a recyclable means to fill this nutrient gap. However, this rapid nitrogen cycle poses concerns for manure application. An appropriate and timely application is necessary so that there is optimal nutrient efficiency.

Fertilizer use and potential subsequent nitrogen loss within the soil is of efficiency and environmental concern (Tilman et al., 2001). Currently, nitrogen from applied fertilizer can be lost through water leachate as nitrate, creating environmental concerns. Nitrate that is not used by the plants is lost into the water, creating environmental concerns among aquatic ecosystems. As far as efficiency, there is much concern because the amount of applied nitrogen is not used
entirely by the plant, therefore, the need to control nitrogen mobilization is higher than ever. Nitrogen mobilization creates issues because of the rapid nature of the process. Tools are needed to either slow or disrupt the cycle, in order to give the plant a good shot of using the available form of nitrogen.

Animal manures have been used to add nitrogen, phosphorus, and potassium, and decrease dependency on synthetic fertilizers. This gives it a key role in sustainable agriculture (Andersen, 2013). Proper animal manure application timing is essential in nutrient management planning. If manure is applied late into the season, such as the freezing months of winter, the risk nutrient loss increases. It is believed spring manure applications experience less nitrate loss than fall and winter applications (Liu et al., 2017). However, the applied nitrogen is often not used entirely by the cropping system, which has led farmers to use alternative methods to efficiently capture available nitrogen. One way to mitigate nitrogen loss, in addition to proper manure application timing, is to use a nitrification inhibitor. These work to reduce the conversion rate of ammonium to nitrate, reducing the loss of nitrogen. This is due to the amount of applied nitrogen in the ammonium form is maintained (Nelson et al., 1992). Nitrification inhibitors may have the potential to improve efficiency in crop production because of its ability to control the movement of nitrogen in the soil, giving the plant a better opportunity to utilize the fertilizer.

Nitrification inhibitors are of large interest because they can be used to manage nitrogen within soils and mitigate nutrient loss (Sassman, 2014). One of the more common nitrification inhibitors is nitrapyrin, which is typically labeled as N-Serve, produced by Dow AgroSciences. Specifically, it inhibits *Nitrosomonas sp.*, a bacterium that oxidizes ammonium to nitrite, which disrupts the nitrogen cycle, increasing the potential N availability for plant growth (Sassman, 2014; Wolt, 2000). Numerous studies have been completed to demonstrate the effectiveness of
nitrification inhibitors, specifically in corn grain yield and reduction of nitrogen loss (Warren et al., 1980).

There is value in understanding practices that reduce overall nitrogen loss from the soil, as it can assist both researchers and farmers that want to improve the amount of nitrogen retained by the plant, increasing efficiency in crop production. There are benefits of nitrification inhibitors, such that “corn yields are often increased as N losses from soils are reduced by the application of nitrification inhibitor with both conventional tillage and reduced tillage systems” (Nelson et al, 1992).

**Objective**

We reviewed and performed a meta-analysis of existing literature to assess the impact nitrification inhibitor rate within fertilizer application has on crop yield. Various factors were included: fertilizer source and rate, timing, and method of application were analyzed to determine trends in corn yield. Each of these factors will give a better understanding of nitrification inhibitor use and fertilizer application, in order to provide recommendations for individuals wanting to incorporate best nitrogen management practices. There is a need to understand the constraints associated with fertilizer application to efficiently capture nitrogen applied.

**Methodology**

A meta-analysis of published literature was performed to assess the impact that manure application timing has on crop yield in the following growing season. In addition, nitrification inhibitors have been analyzed to determine their role in mitigating the loss of nitrogen loss. If
nitrification inhibitors have the potential to maintain corn yield, while managing nitrogen content, they can be integrated into current cropping systems confidently.

In the eighteen studies included, nitrification inhibitor rates ranged from 0.49 L/ha to 5.49 L/ha, which were grouped into three categories: zero, low (0.01-2.00 L/ha), and high (> 2.0 L/ha). These ranges were to create three distinguishable levels of inhibitor rate, to give a better understanding to what kind of rate range is needed to elicit a yield change. Nitrogen fertilizer, including liquid swine manure, anhydrous ammonia, urea, urea ammonium nitrate, and sodium nitrate, application rates were categorized into three ranges: <130, 130-170, and >170 kg/ha. These ranges were selected based on current fertilizer rates for various systems. Typically, 150 kg/ha would be for corn-soybean cropping systems, but on the other hand, 200 kg/ha would be sufficient for continuous corn production. Nitrogen applications were separated by time of application: early fall, late fall, and spring as to show trends within specific timing. In addition, fertilizer sources were grouped into three categories: liquid swine manure, other (anhydrous ammonia, urea, urea ammonium nitrate, and sodium nitrate), and no application, to evaluate impact on corn yield.

Table 2: Factor description

<table>
<thead>
<tr>
<th>Factor</th>
<th>Categorical Levels/Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrification Inhibitor Rate</td>
<td>Zero, low (0.01-2.00 L/ha), high (&gt; 2.00 L/ha)</td>
</tr>
<tr>
<td>Fertilizer Application Rate</td>
<td>&lt;130, 130-170, and &gt;170 kg/ha</td>
</tr>
<tr>
<td>Time of Application</td>
<td>Early fall, late fall, spring</td>
</tr>
<tr>
<td>Fertilizer source</td>
<td>Liquid swine manure, other (anhydrous ammonia, urea, urea ammonium nitrate, and sodium nitrate), no application</td>
</tr>
</tbody>
</table>
Each factor was fixed in JMP, with corn yield being the response variable. An analysis of variance (ANOVA) was used to determine the least square means and standard error means.

Results and Discussion

Instinct Rate Impact on Corn Yield

Instinct rate was divided into three categories: zero, low (0.01-2.00 L/ha), and high application (> 2.0 L/ha). High levels of nitrification inhibitor application resulted in, on average, the highest corn yield, 8.9 Mg/ha. This was a statistically significant increase from zero application of nitrification inhibitor, which was 7.2 Mg/ha. In addition, the high level of nitrification inhibitor was statistically higher than the low application, which was 7.9 Mg/ha.

According to this data set, a higher application rate of nitrification inhibitor results in higher corn yield, on average. This is likely because the nitrification inhibitors slowed the conversion of ammonia to nitrate, allowing for greater nutrient uptake for the plant. Higher nutrient uptake appears to result in greater corn yield, contributing to the idea nitrification inhibitors may be used successfully in a cropping system. The corn yield of each rate is illustrated in Figure 1.
Figure 3: Instinct rate range (L/ha) effect on corn yield (Mg/ha). Shared letters show no significant difference in treatment mean result.

**Nitrogen Application Rate Impact on Corn Yield**

When applying fertilizer, it’s important to understand how the rate of nitrogen application affects corn yield. There are several levels of application rate, based on the type of cropping system: 150 kg/ha would be for corn-soybean cropping systems, but on the other hand, 200 kg/ha would be sufficient for continuous corn production. We chose to look at nitrogen application rate to better understand the impact different levels have on corn yield. We separated levels of nitrogen application rates into four categories: zero, <130, 130 to 170, and > 170 kg/ha.

The highest average corn yield was 8.79 Mg/ha in the application rate greater than 170 kg/ha. The next highest corn yield was 8.76 Mg/ha, which was from a nitrogen application rate between 130 and 170 kg/ha. The lowest corn yield, 7.16 Mg/ha, was from the application rate of less than 130 kg/ha. The zero application of nitrogen fertilizer resulted in 3.4 Mg/ha.
Nitrogen Application Timing Impact on Corn Yield

There are many times a farmer can choose to apply fertilizer to their soil systems. To understand the impact manure application timing has on corn yield when used with and without a nitrification inhibitor, all papers were categorized as either an early fall, late fall, or spring application. These are illustrated in figure 2. The majority of the data points came from a spring application, followed by late fall, and then early fall. Highest corn yield was due to fertilizer applied in early fall, coming at 11.3 Mg/ha, which was statistically higher than the late fall and spring applications, which were 8.1 and 7.2 Mg/ha, respectively. The most realistic timing, according to farmers, is late fall due to the potential prolonged summer season. According to this meta-analysis, it is best to apply fertilizer earlier in the fall if the crop is done and the soil is ready.

Figure 4: Nitrogen rate range effect on corn yield (Mg/ha); Shared letters show no significant difference in treatment mean result.
Figure 5: Fertilizer application timing effect on corn yield (Mg/ha); Shared letters show no significant difference in treatment mean result.

Fertilizer Type Impact on Corn Yield

There are many types of fertilizers that a farmer can choose to use in their cropping system. A farmer can choose to use anhydrous ammonia, which is a gas that is injected into the soil. However, there are storage and handling challenges because of the risks that come with exposure to this dangerous chemical (Baker, 1993). Another option is liquid swine manure, which can be applied by injection or broadcast on the soil. It may be preferred to anhydrous ammonia, as it is a recyclable form of fertilization. Also, urea ammonium nitrate, urea, and sodium nitrate are forms of fertilization used in these studies, which were placed into the “Other” category along with anhydrous ammonia. Average application rate for each means of fertilization was taken into consideration, as the amount of nitrogen applied and available will have an impact on corn yield. According to this meta-analysis, highest corn yield was a result of liquid swine
manure, coming to 9.6 Mg/ha, compared to no application, which had a resulting corn yield of 3.4 Mg/ha. All other fertilizer sources resulted in 7.9 Mg/ha. These three categories are illustrated in figure 3.

Figure 6: Nitrogen source effect on corn yield (Mg/ha); Shared letters show no significant difference in treatment mean result.

Conclusion

Based on the studies included in this meta-analysis, we can recommend the use of a nitrification inhibitor for nitrate retention without an expense to corn yield (Figure 1). It is clear a higher or more aggressive rate of nitrification inhibitor resulted in a statistically significant higher corn yield, as compared to zero use of inhibitor. Highest corn yields were as a result of
early fall, followed by late fall, and then spring applications. This may have something to do with residual nitrogen from the summer cropping season, leading to a higher nitrogen content and following corn yield. I would challenge this, as it seems that a spring application may be favorable, as to prepare the soil for summer cropping season. I would recommend more data points are contributed to this meta-analysis, to get an even richer data set.

Nitrogen source and rate were of interest in this paper. Liquid swine manure applications produced the highest corn yields, as compared to all other sources including anhydrous ammonia, UAN, urea, and sodium nitrate. A nitrogen rate of either 130-170 or greater than 170 produced the highest corn yields, though not significantly different from each other. It can be inferred that a “more is better” mentality does not apply here. It is crucial to apply an efficient amount of nitrogen, as to not waste or receive diminishing returns.

We can recommend the use of a nitrification inhibitor if used with appropriate nitrogen management techniques. These include optimal fertilization timing, nitrogen source, and rate of application. Each of these factors needs to be considered when applying fertilizer to mitigate risks of nutrient loss, environmental hazards, and reduced yield productivity.
References


Andersen, Daniel S. (2013). *A County-Level Assessment of Manure Nutrient Availability Relative to Crop Nutrient Capacity in Iowa: Analysis of Spatial and Temporal Trends, Agricultural and Unite*


CHAPTER 4. EFFECT OF BIOCHAR AND ANIMAL MANURE ON NITROGEN LOSS FROM SOIL

Abstract

Animal manure is used as a fertilizer to add nitrogen, phosphorus, and potassium to soil systems. However, Midwestern farmers are often concerned about the efficiency of their fertilizer application. Another option suggested is biochar, which can be added to soil systems to provide soil structure and nutrient retention. The relationship between biochar and liquid swine manure application and its effect on total NO$_3$-N loss was investigated in this study. For eight weeks, soil columns were leached with 300 mL water to determine cumulative NO$_3$-N loss of soil alone, biochar amended soil, swine manure, and a combination of biochar and swine manure. There was one rate of liquid swine manure and biochar used. All data points were analyzed to give total NO$_3$-N loss from each column, on average. In this study, it was determined that swine manure increased the amount of NO$_3$-N lost from the soil, the addition of biochar to swine manure treated soil decreased total NO$_3$-N. It is suggested that biochar has the ability to reduce cumulative NO$_3$-N loss from soil columns, when soils are fertilized with liquid swine manure.

Introduction

In the United States and globally, there is a high need for food crops, creating a massive agriculture industry and concerns to go with. With millions to feed, there are millions of acres to meet these demands. In Iowa alone, there are millions of acres dedicated to food crops (United States Department of Agriculture – National Agriculture Statistics Service Information -Table 1, 2017). If there are that many acres being used for food production, there can be several concerns as far as environment goes. There can be a high risk of environmental problems, such as water
quality concerns due to nutrient leaching, leading to recent research and development of solutions to mitigate the risk (van der Werf and Petit, 2001). There has been development in methods to mitigate nutrient loss risks, such as specific application timing, nitrogen source, or biochar. Biochar may have the ability to reduce nutrient loss and contamination into groundwater.

Biochar is produced from biomass without oxygen by pyrolysis, by high temperatures, and is primarily made of carbon (Fidel, 2015; Brown and Wang, 2017). The solid product of the biomass subjected to high temperatures is biochar, considered a soil amendment. Biochar can control the movement of nutrients, sequester pesticide residue, increase sorption potential, and reduce overall environmental risk (Brown and Wang, 2017; Wu et al., 2018; Oldfield, 2018, Laird, 2008). Biochar has demonstrated the ability to hold carbon for long periods (Kauffman et al., 2011). It is a highly porous charcoal that can retain water and nutrients, along with the suppression of greenhouse emissions, demonstrating its potential to be incorporated into a sustainable system (Biochar International, 2018; Feng and Zhu, 2017; Kammann et al., 2017).

The management of the nitrogen cycle is of interest to those in the cropping industry. When nitrogen is applied as liquid manure, it is in the form of ammonium, which is oxidized into nitrite, and further oxidized to nitrate. This is the form that is commonly lost from soils. It is important to develop solutions that can reduce the risk of nitrogen loss from animal manures. Biochar has demonstrated the ability to improve the nitrogen cycle and to reduce the amount of nitrogen loss (López-Cano et al., 2015). If biochar is able to be used to disrupt this cycle by holding onto water and the nutrients within it, it may increase the amount available for the crops, increasing crop yields.
The beneficial effect that biochar and animal manure have on nutrient loss and soil quality has been evaluated (Laird et al., 2010). It is important to understand this interaction, as manure is a dominant industry in Iowa. Iowa is a leader in swine production, thus creating a great amount of manure available (United States Department of Agriculture, 2019). Manure is used as fertilizer, as it provides plant available nitrogen, phosphorus, potassium for soils, contributing to increased crop yields (Barnhart, 2001, McCormick et al., 1984; Sawyer, 2001). It is considered an environmentally friendly way to fertilize land, decreasing the dependence on synthetic fertilizers.

The use of manure on land closes the nitrogen cycle through recycling, improving sustainability (Regan and Andersen, 2014; Alam and Chong, 2010). Animal manures can be considered an excellent resource for crop nutrients, further building confidence in using it in crop rotations (Sawyer, 2007). However, with animal manure application, there is a potential for nutrient loss. This loss needs to be addressed with proper application timing, methods, and other nutrient retention strategies. These strategies may include nitrification inhibitors, spring applications, or biochar.

Sustainable agriculture programs depend on the proper implementation of this recyclable material, manure (Eigenberg et al., 2002). If not used efficiently, nutrients, such as nitrogen, can be lost due to its high mobility. Manure is an excellent source of nitrogen, creating the need for tools that can assist in retention for efficiency purposes. If biochar has the potential to retain nitrogen and reduce nutrient loss, we believe it can be used efficiently with manure application, providing a use for both organic wastes (Bahvisha et al., 2019; Pietro et al., 2014).
Objective

The objective of this study was to examine the effect biochar, when used with swine manure, has on NO$_3$-N loss in soil. Nitrogen is an extremely important nutrient for crop productivity. Nitrogen is a highly mobile nutrient, meaning the risk of loss and subsequent contamination is high. This risk increases the need for nutrient management studies. The results of this study intend to provide recommendations for the proper use of both biochar and animal manures.

Methodology

The experiment was performed on Iowa State University’s campus, in the Manure Management Laboratory in Elings Hall. A structure was made of wood and held 12 PVC pipes with 15.25 cm diameter. Each were filled with 5 cm gravel rock and sand to prevent soil fallout, followed by approximately 2000g of soil. The soil was collected in the spring from the Iowa State Agricultural Engineering and Agronomy farm located in Boone, Iowa. Soil series is Clarion and in a plot that had been soybean the previous year and on which rye cover crop had been grown. The bulk density of the soil was 0.95 g/cm$^3$.

There were two factors: liquid swine manure and biochar. An interaction between biochar and liquid swine manure was evaluated. Control replicates were used, which had soil only. In each designated column, 5 grams of biochar and 30 mL of liquid manure was pipette applied with a targeted rate of 6000mg/1L, with an assumed nitrogen availability of 90-100% (Sawyer, J.E., and A.P. Mallarino, 2008). Treatments were laid out as followed: three replicate columns of soil only, three replicates of biochar amended soil, three replicates of liquid swine manure applied, and three replicates of biochar amended soil with liquid swine manure.
Table 3: Liquid Swine Manure Properties

<table>
<thead>
<tr>
<th></th>
<th>TS</th>
<th>TS</th>
<th>TKN</th>
<th>NH4</th>
<th>NTP</th>
<th>PO4-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>mg/l</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>7.6</td>
<td>6.3</td>
<td>6700</td>
<td>5800</td>
<td>2700</td>
<td>1400</td>
<td></td>
</tr>
</tbody>
</table>

One week after manure and biochar application, the columns received 300ml water to first soak the soil. No leached water was collected. Each week, 250ml of water was poured into each column and allowed to fully drain into a glass bottle. When the columns were finished leaching, the mass of water in each glass bottle was weighed and recorded. A subsample of 50mL was collected into the corresponding labeled small plastic bottles. This was repeated for each sample.

After all subsamples were collected, 5ml of 2M monoammonium phosphate (NH$_4$H$_2$PO$_4$) and 1 mL of nitrate stabilizing solution was added to each bottle. Calibration solutions of 10, 100 and 1000 mg-N/L were prepared and used to create calibration curves. These curves were used to determine nitrogen concentration, as it is inversely proportional to the voltage reading from the Oakton Ion 700 benchtop meter (EPA, 2007). With this calibration curve, the x is the log10 value of N concentration and y is the Oakton voltage reading. Once N concentration (mg-N/L) is calculated, it is multiplied by mass leachate (mg/L).

Mass amount of NO$_3$-N per volume was converted to kilograms per hectare. This conversion was to demonstrate the mass of nitrate leached within a specific area, known as specific density. In addition, this unit gives us the ability to normalize for the concentrations given in varying amounts of water leached through each column. An analysis of variance in JMP was used to determine least square means, standard error means, and total cumulative loss per column. To
determine the effect of biochar and manure application, a two-factor analysis was completed, with soil type as a random effect factor, manure as a fixed factor, biochar as a fixed factor, and manure*biochar as a fixed factor.

**Results and Discussion**

An analysis of variance was completed to determine the effect of both biochar and swine manure on the amount of cumulative NO$_3$-N leachate. Results indicated NO$_3$-N leached from columns with just soil was 85.8 kg/ha, per column, on average. Biochar showed a statistically significant reduction in cumulative NO$_3$-N leachate as compared to soil alone, from 85.8 to 79.1 kg/ha. The cumulative amount of NO$_3$-N leached due to swine manure application only increased 55.1% to 133.5 kg/ha, per column, on average (Figure 1). Comparing biochar used with swine manure to that of swine manure only, the amount of NO$_3$-N was reduced by 2.9%, to from 133.5 to 102.9 kg/ha. This reduction shows the potential for use of both biochar and swine manure in the same soil.

The application of liquid swine manure resulted in a higher NO$_3$-N loss, which was to be expected due to the relatively high nitrogen content within manures. However, the addition of biochar to manure applied columns significantly reduced total NO$_3$-N loss by 23%, to 102.9 kg/ha. This is the biggest takeaway from this study. At every time point, the addition of biochar to swine manure treated soils reduced the amount of NO$_3$-N loss. It is important to note that a moderately high rate of biochar was used, which may not be feasible in field application. This demonstrates the need to define a clear application rate for farmers in field settings.
Figure 7: Progressive NO$_3$-N loss by Treatment; Shared letters show no significant difference.

**Conclusion**

From this study, it is suggested that the use of biochar provided soil amendment and provided nutrient retention capabilities when used alone but has the potential to reduce nutrient loss from swine manure application. Nutrient loss is of utmost concern for farmers, so data demonstrates potential to mitigate this risk provides confidence. Biochar may have a use in managing nitrogen within liquid swine manure applications.
References


Fidel, Rivka Brandt, "Biochar properties and impact on soil CO2 and N2O emissions" (2015). Graduate Theses and Dissertations. 14812. https://lib.dr.iastate.edu/etd/14812


CHAPTER 5. CONCLUSION

The final section of this thesis will discuss the results and recommendations from the research papers completed. All recommendations regarding cover crop use with manure application timing will be outlined and described in this chapter, for field applications. In addition, recommendations for the use of nitrification inhibitors in cropping systems will be made as a result of the meta-analysis completed. Lastly, practical uses for biochar and manure will be described to provide confidence for their incorporation into soils.

Implications of Cover Crop and Specific Manure Application Timing

Cover crops were used on approximately 1.5 million acres in Iowa in 2017, which is greatly higher than ten years ago, when less than 10,000 accounted for cover crop plantings (Iowa Nutrient Research and Education Council, 2017). The use of cover crops is rising, but it is crucial to continue investigating their impact to provide confident recommendations. Farmers want to feel assured that cover crops can be used beneficially with swine manure application to reduce nitrogen loss. Nutrient loss is of utmost concern for farmers, as it can contribute to losses in efficiency and yield.

The research presented in chapter two, “Evaluation of the Impact of Cover Crop and Manure Application Timing on NO$_3$-N Loss in the Midwestern US”, suggests that the use of a cover crop may reduce the amount of NO$_3$-N lost as nitrate from the soil. This mitigates nutrient loss risk and potential contamination into groundwater. In addition, the risks of using animal manure in soils without a means to scavenge excess nitrogen are apparent. The amount of NO$_3$-N
lost from the soils treated with animal manure alone was greater than that of soil alone. This sets the stage as to why this study was completed in the beginning.

Looking at the various timings of manure application, there were no significant differences between the first two application timings, for the first few weeks that they were leached. When the third application timing was performed, there was no significant difference in NO$_3$-N loss either. The most delayed application of manure had the least cumulative amount of nitrogen lost from the soil. This could have been expected, as this manure was not applied until four weeks into leaching had begun.

However, even with the delayed manure application, the amount of NO$_3$-N loss was lowest in the soil with a four-week delayed manure application. It is possible that a more developed cover crop is more successful in retaining NO$_3$-N. In conclusion, this suggests that the age of the cover crop may have a role in the amount of nitrogen loss, but that the timing of manure application has greater implications for nitrogen loss.

These results give way for future studies regarding cover crops and animal manure. A suggestion is that another round of leaching experiments is completed, but for a longer amount of time, i.e. 12 weeks. We saw in the last week of leaching that the immediate and two-week delayed application resulted in nearly the same amount of cumulative NO$_3$-N loss, but it would be beneficial to see the results beyond eight weeks. Swine manure is heavily used in Iowa, but it may also be beneficial to investigate various types of manure, such as poultry or beef, to compare results. Using other types of cover crop may be useful as well, to study the behavior of several genotypes.
In conclusion, we want to recommend the use of cover crops in a system with manure application. More research has to be done in order to do this. Increasing the use of cover crops is beneficial for the quality of the soil, drawing its attention in sustainability studies.

**Recommendation for the Use of Nitrification Inhibitors**

Nitrification inhibitors were used on 70% of Iowa fields to keep fall applied fertilizer in place, but it is important to continue building confidence and investigating their use and benefits (Iowa Nutrient Research and Education Council, 2017). Based on the studies included in this meta-analysis, we can recommend a nitrification inhibitor for nitrate retention, without detriment to corn yield. A higher rate of nitrification inhibitor, greater than 2.0 L/ha, resulted in a statistically significant greater corn yield, as compared to zero use of inhibitor. According to this study, applying fertilizer in the early fall resulted in highest corn yields, followed by late fall, and then spring applications. This may have something to do with residual nitrogen from the summer cropping season, leading to a higher nitrogen content within the soil at time of application. I would challenge this, as spring applications may be more beneficial, as it could prepare the soil for summer cropping season.

Various sources of fertilizer were included in this study, including liquid swine manure, anhydrous ammonia, UAN, urea, and sodium nitrate. Liquid swine manure applications produced the highest corn yields of all sources. Of the rate ranges of nitrogen application, the rate between 130-170 kg/ha and greater than 170 kg/ha produced the highest corn yields between the two. There was no significantly difference between the two, which makes this type of information is valuable to farmers. It is crucial to apply an efficient amount of nitrogen. This is to not waste or receive diminishing returns in corn yield.
We can recommend the use of a nitrification inhibitor, if used with optimal nitrogen management techniques. These include optimal fertilization timing, nitrogen source, and rate of application. Each of these factors need to be considered when applying fertilizer in order to mitigate risks of nutrient loss, environmental hazards, and reduced yield productivity. Going forward, I would recommend that more data points are contributed to this meta-analysis, to get an even richer data set.

**Practical Uses for Biochar and Liquid Swine Manure in Field Applications**

There is a need to develop tools to reduce nitrogen loss in soils, to provide better cropping efficiency. Crops depend on a steady supply of nutrients such as nitrogen, phosphorous, and potassium, creating a need for efficient fertilization. There is potential for biochar to be used as a means to amend soils and improve water and nutrient retention, such as nitrogen. Biochar is made by pyrolysis by recycling nutrients from organic waste, rich in carbon, and offers the potential for soil carbon sequestration (Oldfield, 2018). These benefits describe why biochar was selected for this study.

When animal manures are applied to the soil, there can be a risk of nutrient loss due to the rapid nitrogen cycle within the soil. This cycle oxidizes atmospheric nitrogen, N2, to ammonium, NH4, and then further to nitrite, NO2, and nitrate, NO3. This happens quickly, which puts nitrogen loss at a risk from the soil. If nitrogen is not used properly by the soil and plants, it is lost by denitrification or leaching into groundwater. This causes concerns of contamination. If there is a way to mediate this risk, it is worth investigating.

We examined the relationship that biochar and animal manure have by collecting leaching data over eight weeks. We found that the use of biochar on soil alone reduced the
amount of nitrate-nitrogen lost over eight weeks, both cumulatively and weekly. When animal manures are used, the amount of nitrate-nitrogen lost from soil was significantly greater than all other treatments. The important piece of information from this research paper is the result that biochar reduced the amount of nitrate-nitrogen lost from the soil, as compared to the swine manure treated soil. This demonstrates the potential for biochar’s ability to retain nitrogen.

Summary

There are many tools that address nitrogen management concerns, which have been the focuses of this thesis. Cover crops may be used to prepare the soil for manure application, allowing for better nutrient retention. Nitrification inhibitors are a great addition to nitrogen fertilizers that disrupt the nitrogen cycle, allowing for more efficient application. Lastly, biochars have the ability to retain water and nutrients in the soil, when used with swine manure. Each of these tools have the potential to improve nitrogen management, improving the efficiency of manure application procedures.
References
