Not All Litter is Created Equal: Differences in Nitrogen Mineralization Among Broiler Litter Types

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ABSTRACT

Over three fourths of U.S. broiler chicken production is located in the Southeast and generates a substantial amount of broiler litter (BL). Broiler litter is a mixture of bedding material and manure that can be a valuable nutrient source for row crop production when properly used. New technologies provide farmers with the opportunity to use a combination of BL and inorganic fertilizers with minimal environmental impact. The first part of the project evaluated integrated N management systems that incorporate ammonia control technologies (ACT), nitrapyrin, and irrigation. A laboratory incubation of amendments with soil was conducted to determine the effectiveness of nitrapyrin treatment of ACT and normal litters at inhibiting nitrification in litter amended soils. Treatments for the study were a factorial combination of litter type (ACT, normal, none), nitrapyrin (with and without), and soil moisture (optimal at 75% field capacity and sub-optimum at 40% of water holding capacity). There were 5 replications and all treatment combinations were incorporated into the soil at a rate of 168 kg ha^{-1} PAN. Soils were incubated at 25 C for 16 weeks with bi-weekly adjustments to desired soil moisture conditions. There were seven sampling dates with separate incubation units for each sample date. On each sample date a cup from each amendment combination and block were removed and the soil pH, moisture content, Urea-N, NO_3-N, and NH_4-N concentrations were determined on an as is sample. The rest of the sample was analyzed for organic matter and total N. The results obtained from this study indicated that the inhibitors were very effective for four weeks and maintained some efficacy up to almost eight weeks. The combined effect of the inhibitor and the N source was significant at week eight, which demonstrates that for some N sources nitrapyrin maintained its effectiveness into week eight. This is significant for crop producers since most apply BL in cooler months. The soil moisture content had a significant impact across all sample dates and the effect of the N source was significant at weeks eight through 16. There was an interaction between N source and soil moisture in weeks two and four. The higher target moisture content (75% field capacity) generated more nitrate regardless of the other treatments over the course of the study which leads to the conclusion that the wetter the soil, the more nitrate that will be produced. We are currently conducting a follow up incubation to look at N mineralization rates across different types of BL, specifically focusing on the bedding material used in the poultry houses. This study will also look at the rate of amendment applied to see if it influences the rate of N mineralization.

INTRODUCTION

In Kentucky, most soils do not supply enough N for the non-legume crops grown and most cultivated soils in Kentucky range from 0.05 to 0.10% N, but only a small portion of this is available during the growing season (Wells et al., 1997). Kentucky soils usually remain wet through the winter and do not freeze completely which creates opportunities for loss of residual inorganic N prior to planting in the following spring (Murdock and Ritchey, 2014). The poultry industry developed rapidly in Kentucky about three decades ago (Rasnake, 1996) and Kentucky was seventh in the nation for broiler production with 308 million broilers in 2014 (NASS, 2017). There are around 3,000 houses in Kentucky (Federation, 2017) which means that annually there are about 450,000 tons of BL produced in Kentucky every year. Most of the poultry production occurs in the area of the state where corn production is concentrated (Rasnake, 1996). This makes BL an available, and with proper management, an economical source of nutrients, especially N (Shockley, 2016).

Broiler litter is a high value manure in terms of nutrient content. It contains key macro and micronutrients that plants need (Wells et al., 1997). Applying BL to cropland has been shown to increase soil organic matter, increase the cation exchange capacity (CEC), and increase the buffer capacity of the soil (Havlin et al., 2014; Magdoff and Van Es, 2009). These factors lead to an increase in yield when using BL when compared to synthetic fertilizers when used in at the proper time in the proper amount (Rasnake et al., 2004). The higher yield and long-term benefits of applying BL as fertilizer make it an economical choice for most crop producers in Kentucky. This will depend on the location of the poultry production houses and transportation costs. Much of the productive agronomic land in Kentucky is located in close proximity to poultry production which makes BL an economically beneficial source of nutrients. The best practices depend on the crop grown, soil type, and access to BL (Havlin et al., 2014). It is usually best to incorporate BL in combination with synthetic fertilizers to supply all the necessary nutrients needed for your crop (Rasnake et al., 2004). With proper application rates and application timing, crop producers see economic benefit from applying BL as fertilizer in Kentucky.

Many factors affect the N content of the BL. The storage practices, poultry production practices, stockpiling and cleanout schedules, application timing, and application method are just a few of the factors that influence the amount of N as well as the rate of N mineralization in the soil after BL application (Hubbard et al., 2008; Nahm, 2003; Nahm, 2005). To calculate the fertilizer value of BL, the inorganic N contents and the mineralizable organic N fraction are added together. The factors that influence the total N content are differences in feed, feed conversion by different species, age of the animal, bedding material and water intake, pH, temperature, and moisture (Leconte et al., 2011). The rate that organic matter is decomposed is affected by the chemical composition of the material decomposing and the soil characteristics where the decomposition is taking place (Douglas and Magdoff, 1991).

In recent years, concerns have grown about the adverse human health and environmental impacts of reactive nitrogen compounds, ammonia, and nitrous oxide emissions from poultry producing facilities and BL applied to cropland. The lost N reduces net N use efficiency and its deposition onto nearby surface waters can contribute to surface water eutrophication. Farmers value the poultry litter generated on their own or nearby farms as an economic source of multiple nutrients critical for high crop yields and need a reliable management system that will allow their continued use in a manner that sustains agriculture and protects the environment. Fortunately, new technologies have emerged that should allow farmers to combine BL and inorganic fertilizers in high yielding production systems with minimal environmental impact. This project evaluated an integrated N management system for high yield corn that incorporates ammonia control technologies (ACT), nitrapyrin, BL, and irrigation. Ammonia control technologies use innovative methods to mitigate NH_3 loss from poultry houses, thus increasing the N value of BL and reducing air and water quality concerns. Conserving NH_3 in poultry houses has other benefits including resource conservation and producing BL with higher N:P ratios which will more closely match crop uptake and thus be less likely to lead to P accumulations in soils. Subsurface poultry litter application is a new approach to inject solid BL into soils, which both reduces N loss via NH_3 volatilization and the potential for P losses in surface runoff. Due to constraints of this lab study, we were unable to include treatments that accurately reflect subsurface injection. The subsurfer offers the unique opportunity to use nitrapyrin in combination with BL. Nitrapyrin can conserve ammonia in soil, reducing nitrification and denitrification, resulting in overall higher N use efficiency by maintaining plant available N in the root zone. Irrigated corn is common in areas with occasional drought and the water content of the soil where BL is applied can influence the N use efficiency of the system. It was unclear how exactly the moisture content would influence the various N sources with the nitrapyrin and ACT additions.

The overall goal of this study was to evaluate the influence of Nitrapyrin, ACT, and soil moisture on N availability in soils amended with BL. Upon completion of this study, a follow up study was designed to look at various litter types and the effect of rate of application. This follow up study is currently being conducted. The follow up study is designed to focus specifically at the bedding material and see how it influences the other factors that dictate the N mineralization rates when BL is applied as a nutrient source. Generally, the bedding material used in poultry houses is obtained locally by poultry producers to be economically viable. Rice hulls are the dominant bedding material used in the Midwest while wood shavings are the dominant bedding material used in the Southeast. Different bedding materials have been studied for use in broiler production, but research on mineralization differences of BL used as a nutrient source is lacking. The first purpose of this study is to evaluate differences in N mineralization rates among BL with different bedding types. The second purpose is to determine the effect of application rate and method on N mineralization rate. Quantifying N mineralization rates and physical properties of BL produced with different bedding materials would allow producers to more efficiently manage and utilize this nutrient source for crop production.

MATERIALS AND METHODS

First Incubation

The first laboratory study was designed to provide specific data to allow better estimates of plant available N in new types of poultry litters, such as those treated with ACT and nytripyrin to reduce nitrate losses and slow the rate of nitrification. It was designed to also assess the impact on soil moisture on N availability from normal and ACT litters to current estimates of litter organic N mineralization should be modified for irrigated production. The BL for this study was obtained from a poultry research farm at the University of Delaware Carvel Research and Education Center. Half of the BL was treated with ACT litter and half was a control litter. The soil was collected from five fields that contained a sandy loam texture and a pH in the range of 5.5 – 6.5; each field represented one block. The soil was collected from the surface six inches, thoroughly mixed, and screened to 7 mm in the field. The soil was be air-dried in the lab after collection. Prior to the incubation study each soil was analyzed to determine cation exchange capacity (CEC), particle size distribution, pH, organic matter (OM) content, total N, urea-N, nitrate-N, ammonium-N, and gravimetric moisture content at field capacity. Treatments were a factorial combination of litter type (ACT, normal, none), Nitrapyrin (with, without), and soil moisture (e.g., optimum ≈ 75% of field capacity and sub-optimum ≈ 40% of field capacity), replicated 5 times. All treatment combinations were incorporated into the soil at a rate of 168 kg ha^{-1} PAN. Soils were incubated at 25 °C for 16 weeks, with bi-weekly adjustment to desired soil moisture conditions. A separate incubation unit was established for each sample date (0, 1, 2, 4, 8, 12, and 16 weeks after amendment). Prior to application of amendments, 500 g of dry soil was added to each incubation cup and the appropriate amount of DI water was mixed into each cup to bring it to the target moisture content. Each cup was incubated at 25°C for 21 days to stabilize the soil microbial communities and inorganic N status. After the pre-incubation the cups were removed from the incubator and weighed; the appropriate amount of DI water was added to return cups to the target moisture content. Nitrification inhibitors were mixed with each soil using the amount of DI water as necessary to achieve the target moisture content. Incubation cups not receiving nitrapyrin were mixed thoroughly with the appropriate amount of DI water to bring the soil to the desired moisture content. The poultry litter was thoroughly mixed with the soils. On each sample date, a cup representing each amendment combination and block was removed from the incubators. Soil pH, moisture content, and urea-N, NO_3-N, and NH_4-N concentrations were determined on an as-is sample. The remainder of the sample was air-dried and sieved (2 mm) and analyzed for organic matter and total N.

Follow Up Incubation

For the follow up incubation, the BL samples were collected from various sources around the state of Kentucky and from surrounding states. The bedding type, stockpiling practices, number of grow outs, inhibitors used, number of flocks, and other important factors were recorded. Each litter was analyzed for nutrient content and chemical characteristics. The soil was pre-incubated at 25°C for 21 days to stabilize the soil microbial communities and inorganic N status. The soil was then analyzed to determine the CEC, pH, total N, Nitrate-N, Ammonium-N, total P, total C, organic matter, gravimetric water content, and texture. The litter was incorporated in the soil based on N content at 100 lbs. of total N per acre or about 2-3 tons per acre and kept at 75% of field capacity. The temperature is set at 25°C and the soil was sieved to 7 mm and the litter was applied as is to accurately reflect the infield practices. The study is a complete factorial randomized complete block design. Each incubator will be considered an experimental block with four blocks. The incubation will occur for 6 weeks or until the samples are observed to be unreliable due to the condition of the incubation cups (or other complications). On each sample date, a cup representing each amendment combination and block is removed from the incubators. Soil pH, moisture content, and urea-N, NO_3-N, and NH_4-N concentrations are determined using destructive sampling. The remainder of the sample is air-dried and sieved and analyzed for organic matter and total nutrient content. Treatments for the first run of incubations included a single litter type with a rice hull bedding material from a full house cleanout. The treatments include a high and low rate of urea, triple super phosphate, BL, and soil only. This incubation was conducted to ensure methods for incubation and analysis were accurate, to establish proper sampling frequency, and to see how rate influences the N mineralization rates. The second incubation will look at the six different litter types collected. The litter collected represents rice hulls and wood chips across three different management treatments. For both rice hulls and wood shavings a litter that is from a full cleanout, a de-crusting windrowed and a de-crusting non-windrowed have been collected. A control of only soil will be included. There will be a treatment with urea and one with triple super phosphate at two rates with equivalent N and P. These treatments will be incubated at 25°C for at least 6 weeks. The sample basis will be based on the prior incubation results. The BL will be incorporated in at least 4 replications and the moisture will be adjusted to maintain 75% of field capacity on a bi-weekly basis to maintain desired moisture conditions.

RESULTS AND DISCUSSION

Results From First Laboratory Incubation

The soil nitrate concentrations revealed that the data should be evaluated across time as the sample week had a significant interaction with many combinations of the main effects. The results indicated that the nitrapyrin inhibitor was very effective for four weeks and maintained some efficacy up to almost eight weeks. The combined effect of the inhibitor and the N source was significant at week eight, which demonstrates that for some N sources nitrapyrin maintained its effectiveness into week eight. This confirmed that effectiveness of nitrapyrin treatment of ACT and normal litters at inhibiting nitrification in litter-amended soils. This incubation was conducted at 25°C, which is warmer than the typical temperature when farmers are applying BL. We would expect nitrapyrin to be more effective at cooler temperatures and so the results are significant for crop producers since most apply BL in cooler months and in the study nitrapyrin was effective even at high temperature. The soil moisture content had a significant impact across all sample dates and the effect of the N source was significant at weeks eight through 16. There was an interaction between N source and soil moisture in weeks two and four. The higher target moisture content (75% field capacity) generated more nitrate regardless of the other treatments over the course of the study which leads to the conclusion that the wetter the soil, the more nitrate that will be produced. The is important because it provides support for using different estimates for N mineralization of BL when applying BL to an irrigated system. The rates were higher in our study and these results will be used to adjust the equation estimates for N mineralization from BL in irrigated systems. The soil ammonium N measurements were lower than nitrate concentrations and were quite variable. These results give us a value for total inorganic N content. There were no statistical differences between the total inorganic N concentrations in the first two weeks as expected since we attempted to apply the same amount of plant available or inorganic N. Statistical differences began to emerge in week four and the inclusion of nitrapyrin decreased total inorganic N across all N sources and soil moisture regimes. There were no significant differences between the N sources as expected since the same amount of PAN was applied in each treatment. The combined effect of N source and target soil moisture content were significant. At week four we see that generally the effect is a function of the high inorganic N concentrations resulting from the high moisture content combined with either standard BL or no N added. This seems to be some sort of laboratory anomaly. After week four the trends disappeared and became more reasonable. The soil moisture content itself had an effect on total inorganic N concentrations in week eight through 12 regardless of other treatment factors. The wet soil always had statistically greater concentration than the drier soil.

This study showed that N mineralization differs between irrigated and non-irrigated production systems. A higher moisture content affects the timing and extent of nitrate production in soils amended with BL regardless of presence or absence of ACT or nitrapyrin. The rate that organic matter is decomposed is affected by the chemical composition of the material decomposing and the soil characteristics where the decomposition is taking place (Douglas and Magdoff, 1991). The order of importance in influencing NH_3 formation of poultry manure litter pH, temperature, and then moisture content (Nahm, 2003). Uric acid and urea are rapidly hydrolyzed to NH_3 and CO_2 by enzymes urease and uricase if the temperature, pH and moisture are adequate for microbial activity (Nahm, 2003). This is in line with previous studies that indicate an increase in N mineralization when the moisture content is within the ideal range of around 40-60% moisture content (Nahm, 2005). Another study indicated that microbial growth in BL below this range results in a decrease in N mineralization (Elliott and Collins, 1983). A study looking at soil moisture regimes found that there was no significant impact on the BL inorganic N content when incubating BL at 60% water filled pore space and at a fluctuating water filled pore space (60%-30%) on three different soil types (Sistani et al., 2008).

This study also showed that nitrapyrin acts as an effective nitrification inhibitor in normal BL and BL with ACT. This shows that nitrapyrin reduces the rate of conversion of NH_3-N added in the BL, as well as NH_3-N mineralized from litter organic N, to nitrate-N. This should increase the efficiency of plant N uptake and decrease nitrate leaching losses. This is a similar result to other studies including nitrification inhibitors. Ju et al. found that DCD was also effective at reducing nitrification. They found that the N fertilizer was mostly fixed in the soil after 35 days but without DCD was present as nitrate (Ju et al., 2004).

Proposed Outcomes from Follow-up Study

The nutrient content of fertilizers is important to crop producers making decisions about crop inputs. If you apply the right amount, but nutrients are not available when the plant needs them, the farmer wastes time and money. The correct nutrient content and predicting nutrient availability of BL is vital to a producer's ability to maximize efficiency and profitability. If producers can apply the optimal rate at the optimal time they will maximize their efficiency. This will decrease the amount they waste and decrease excess expenses, increasing profitability. The results from this study will inform researchers on the comparability of litter studies across different types of litters. The research will help determine if further research should be done on differences in litter types and whether the in-house practices should be taken into account when determining in-field practices. The physical and chemical analysis will be used to determine differences in litter handling between the bedding types. If time allows, the incubation experiment will be repeated to compare incorporated and unincorporated application. The goal of this study is to help researchers ensure they are making accurate comparisons between BL studies and to help crop producers make better decisions when applying BL as fertilizer. The first objective is to identify differences in N mineralization rates and nutrient release among different types of BL. This will help determine if there should be differences in litter handling, application practices, and nutrient value based on the type of BL.

SUMMARY

This study found that nitrapyrin is an effective option for farmers who want to use a nitrification inhibitor and it will likely perform well when used in field conditions in combination with BL injection application method. It is important to note that the soil moisture content had a significant impact and that should be taken into account when applying BL in an irrigated system. The follow up incubation that is currently taking place will further our understanding of the factors that influence the inorganic N mineralization rates in BL applied as a nutrient source. The study will focus on N mineralization rates across different types of BL (bedding materials) and the rate of amendment applied to see if it influences the rate of N mineralization.

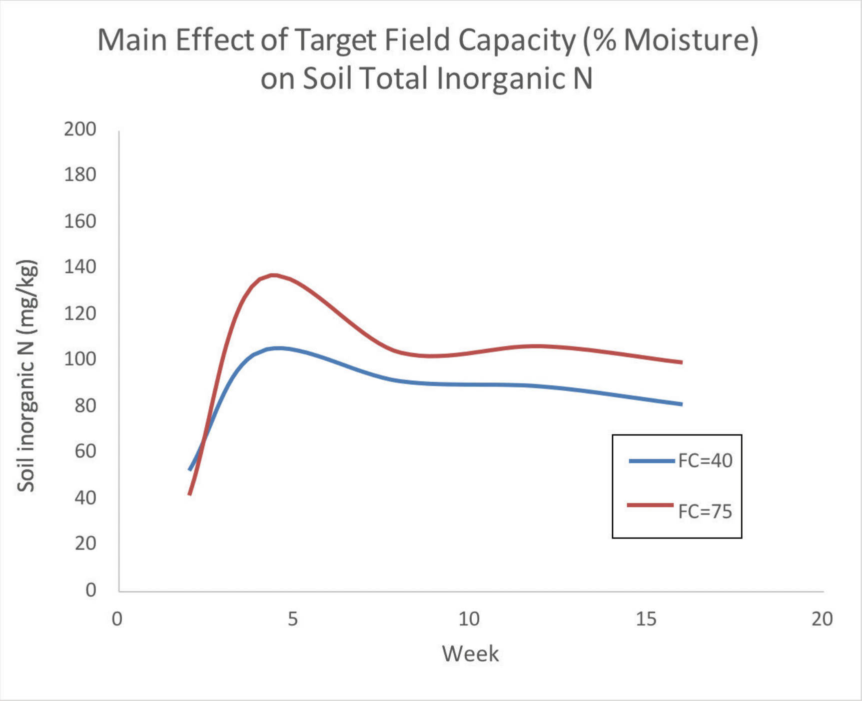

Figure 10. Main effect of soil moisture content on total soil inorganic N concentrations across time

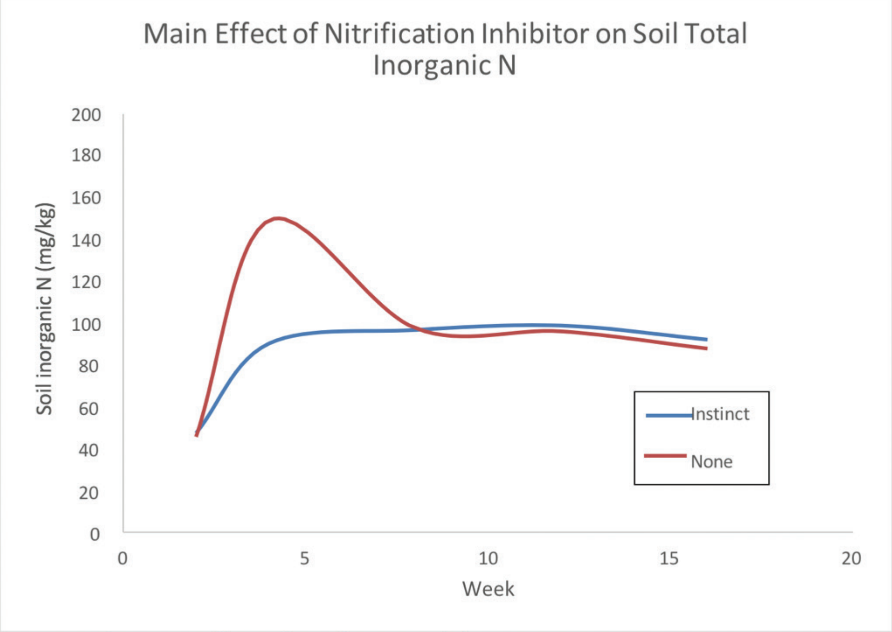

Figure 8. The main effect of nitrification inhibitor on total soil inorganic N concentrations over time

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