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EVALUATING THE LONG TERM EFFECTS OF CONTINUOUS BROILER LITTER APPLICATIONS ON RESIDUAL SOIL FERTILITY AND YIELDS OF CORN AND SOYBEAN CROPS, AND A SIDE EXPERIMENT STUDYING THE RESIDUAL COPPER FERTILIZATION EFFECTS ON THESE CROPS

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Abstract

The increasing cost of commercial fertilizers and the availability of animal waste that has high nutrient content have led to producers utilizing animal waste such as poultry litter in their fertility programs. This increased use has raised concerns as to what are the optimum rates to apply to meet crop needs and how will long term use at high rates of litter effect soil test levels of nutrients such as phosphorus and potassium. The objective of this study was to address these concerns. This study has been ongoing since 1997 with treatments of zero to seven tons of litter being applied in years where corn was planted and then in years where soybeans were planted the residual fertility from the previous years of applications were observed. In 2005, 2006, and 2009; 230 lbs/A of commercial phosphorus (P_2O_5) and 250 lbs/A of commercial potassium (K_2O) were applied to the plots treated with the historical rates of one and two tons per acre of broiler litter. This study looked at the effects residual fertility from past broiler litter applications had on soil nutrient levels and plant nutrient uptake during the 2013 soybean growing season, as well as, the effect on soybean yield in 2012 and 2013. In 2014 the study was returned to corn and the zero through seven tons per acre broiler litter treatments were again applied. Data reported from 2014 included soil test results, R1 corn ear leaf tissue analysis, and yield. In 2007 a positive correlation between soybean uptake of copper and yield was observed. In 2009 a second study to compliment the broiler litter study was started where the effects of pre plant soil applied rates of 0, 10, and 20 lbs/A of copper on soil test copper levels, plant uptake of copper, and yield were evaluated. This study was continued with only yield data being reported for the 2012 growing season and soil test results, plant tissue analysis, and yield data being reported for the soybeans in 2013 and the corn in 2014. Mean soil test values for pH, organic matter, and total nitrogen, though not always significant, tended to be higher in plots treated with the higher rates of broiler litter. Plots treated with the higher rates of broiler litter and those treated with the past rates of one and two tons per acre rates of broiler litter, which also received high rates of commercial phosphorus (P_2O_5) and potassium (K_2O) fertilizers three years of the study, tended to have higher soil test phosphorus and potassium values. No statistical difference in mean soil test calcium values were observed among the one through seven tons per acre rates of broiler litter treatments in either year. Mean soil test magnesium values were highest in plots treated with the four through seven tons per acre rates of broiler litter. In both 2013 and 2014 mean soil test values for zinc and copper were highest in the plots treated with the seven tons per acre rate of broiler litter, then soil test values declined steadily as the rate of litter applied was reduced. Mean soil test values for boron were only collected in 2013, but followed a similar pattern as zinc and copper. Mean values for manganese did not seem to follow a pattern based on fertility, as in both years the highest values came from the no litter treatment, but were not significantly different from other treatments of moderate to high rates of broiler litter. Though not always significantly different, in both years, mean soil test values for iron tended to be lowest in the no litter and three tons per acre rates of broiler litter treatments. No statistical differences from R5 soybean leaf tissue analysis or R1 corn ear leaf analysis were observed for plant uptake of nitrogen, magnesium, calcium, sulfur, zinc, manganese, or iron. Tissue analysis from both years showed that plant uptake of phosphorus was significantly lower in the plots treated with no litter, than in plots receiving any rate of litter. No statistical difference in plant uptake of potassium was observed from soybean tissue samples in 2013, but R1 corn ear leaf analysis in 2014 revealed that plant uptake of potassium was statistically lower in plots that received no litter, compared to plots that received any rate of broiler litter. Boron and copper uptake were statistically lower in soybeans treated with the seven tons per acre rate of broiler litter than the zero through five tons per acre treatments in 2013, but no statistical difference in boron or copper uptake by corn was observed in 2014. No statistical difference in soybean yield was observed among broiler litter treatments in 2012 due to extended dry periods during the growing season. In 2013 the soybeans treated with past applications of seven tons per acre of broiler litter had statistically higher yields than all other treatments except the one ton per acre treatment, which was not significantly different. In 2014, corn that received the five through seven tons per acre rates of broiler litter tended to have higher yields, due in part to the amount of nitrogen supplied by the litter. In both 2013 and 2014 mean soil test values for copper were significantly higher in the plots receiving the 2009 application of 20 lbs/A of copper and the soil test values declined steadily as the rate applied was reduced. Despite the significant differences in soil test copper values, no statistical differences in plant uptake of copper were observed from R5 leaf tissue analysis in 2013 or R1 corn ear leaf analysis in 2014. Although no statistical differences in yield were observed among the treatments from 2012 to 2014, a strong trend was observed where the plots treated with the 10 lbs/A application of copper in 2009, yielded highest among treatments.

Key Words: Broiler litter, Copper, Soybeans, Corn, Fertilization

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Chapter 1

Introduction

Due to the rising costs of commercial fertilizers and the rising amounts of animal waste from poultry houses, applications of broiler litter on agriculture production fields have become more common. Based on the projection of 1,200 poultry houses in Kentucky by 1998, 180,000 tons of litter per year are estimated to be produced (Rasnake, 1996). Nutrient content per ton is based on number of flocks that go through a house in a year's time, which ranges from two to five flocks per year (Rasnake, 1996). Nutrient content of litter ranged from 46 to 56 pounds of nitrogen per ton, 54 to 65 pounds of phosphorus (P_2O_5) per ton, and 54 to 63 pounds of potassium (K_2O) per ton depending on how many flocks went through the house in a year (Rasnake, 1996). In addition to nitrogen, phosphorus, and potassium, broiler litter also contains many secondary and micronutrients (Rasnake, 1996).

As applications of broiler litter become more common, research into how continuous litter use effects crop yield and soil properties will be of value to Kentucky producers. Research in this area is important to determine if nutrients from broiler litter are as available to plants as they are from commercial fertilizers, allowing for comparable if not higher yields. In addition it is also important to know if continuous use of broiler litter will result in abnormally high soil test levels of nutrients such as phosphorus.

With this in mind, in 1997 Dr. John Mikulcik began an experiment at the Murray State University Pullen Farm to address the issues stated above. From 1997 to 2002, eight treatments of zero to seven tons of broiler litter per acre were applied to corn plots with no other commercial fertilizers being applied. In 2003, the rates were cut in half and then in 2004 no treatments were applied. Corn was grown on the plots in 2003 and 2004. Soybeans were planted in 2005 and 2006 with no litter treatments being applied; however, treatments that had previously received one or two tons of litter per acre were treated with applications of 230 pounds per acre of commercial phosphorus (P_2O_5) and 250 pounds per acre of commercial potassium (K_2O). In 2007 no treatments were applied, but a correlation between plant uptake of copper and soybean yield was found (Upchurch, 2008). In 2008 the plots were planted back to corn and the zero to seven tons of broiler litter per acre treatments were again applied. The plots were returned to soybeans in 2009, with no litter applied. The historical treatments of one or two tons of litter per acre treated plots received the same applications of commercial phosphorus (P_2O_5) and potassium (K_2O) applied in 2005 and 2006. In addition, a former Murray State graduate student, Joshua Scott began a second study where copper was soil applied at 0, 10, and 20 pounds per acre rates prior to planting. Both studies have continued since 2009 with no further treatments applied and the plots have remained in soybeans. Both studies are in a randomized complete block design and have 4 replications. Soil and tissue samples were collected from both studies to monitor soil test levels and plant uptake of nutrients. Both studies were taken to yield and analysis of variance was used to analyze the data collected for statistical differences among treatments.

Statement of the Problem:

What, if any, are the long term effects of continuous broiler litter use on crop yield and soil properties? What, if any, are the effects of a 2009 application of 10 and 20 pounds per acre rates of soil applied copper to corn and soybean plant uptake of copper and on crop yield?

Purpose of the Study:

The purpose of this study was to continue, the work started by Dr. John Mikulcik in 1997, monitoring the effects of long-term broiler litter use on crop yield and soil properties. The broiler litter study examined the residual effect of past treatments of zero to seven tons per acre of broiler litter on soybeans in regards to soil nutrient values, plant tissue nutrient values, and yield. In years when the plots were planted to corn, treatments of zero to seven tons of broiler litter were applied. In addition to the broiler litter study, a second study, continuing the work started by Joshua Scott in 2009 in which pre-plant treatments of liquid copper at 0, 10, and 20 pounds per acre rates were applied to soybeans, was conducted to examine residual effects on yield from those 2009 treatments.

Research Questions/Hypotheses:

Hypothesis 1

$H_0$1: There will be no statistical differences in the crop yields, soil test nutrient values, and plant tissue analysis nutrient values in the plots with the higher rates of broiler litter than those receiving the lower rates of broiler litter and commercial P and K.

$H_1$1: There will be statistically higher crop yields, soil test nutrient values, and plant tissue analysis nutrient values in the plots receiving higher rates of broiler litter than in the plots receiving the lower rates of broiler litter and the commercial fertilizers.

Hypothesis 2

$H_0$2: There will be no statistical differences in crop yields, soil test copper, and plant tissue analysis copper among the plots with the two treatments of soil-applied copper and the untreated check plots.

H_12: There will be statistically higher values for soil test and plant tissue analysis copper, as well as higher yields in the plots treated with the two rates of soil-applied copper than the untreated check plots.

Theoretical/Conceptual Framework:

The framework of this study was based on the protocol of the original primary investigator Dr. John Mikulcik. The treatments of zero to seven tons of poultry litter per acre to corn were developed by him. The move to use soybeans in place of corn was based on the work of Adeli et al. (2005) examining broiler litters effects on soil nitrogen and phosphorus and soybean yield.

The copper study is a side project that originated from findings from the long term broiler litter use research. In 2007 Matt Upchurch, a former Murray State graduate student working on the broiler litter study, observed a correlation between levels of plant tissue analysis copper and soybean yield (Upchurch, 2008). In 2009 Joshua Scott, also a former Murray State graduate student working on the long-term broiler litter use study, began the copper study when he applied pre-plant treatments of 0, 10, and 20 pounds per are rates of liquid copper to soybeans and observed the effects of the treatments on soil test and plant tissue analysis copper and yield (Scott, 2010). The 2009 treatments were the only applied and all years that followed have looked at the residual effects.

Assumptions:

1.) All applications of treatments were made uniformly.
2.) All herbicide treatments were applied uniformly.
3.) Entire plot has had the same tillage history (No-Till).
4.) All data was collected as accurately as possible.
5.) Insects and disease will not be a problem.

Definition of Terms:

Broiler Litter- The mixture of poultry manure and bedding material removed from poultry houses.

Soybean Growth Stage V5- Vegetative state of soybeans where plant has five fully developed trifoliates.

Soybean Growth Stage R1- Soybean has one open flower at any node on the main stem.

Soybean Growth Stage R6:- Plant has pod with a green seed that fills the pod cavity on one of the four uppermost fully developed trifoliates on the main stem.

Soybean Trifoliate- A soybean leaf comprised of three leaflets.

Tasseling- Corn growth stage were the last branch of the tassel is completely visible, but the silks are not yet visible.

Delimitations:

1.) The study is designed to evaluate the long term effects of continuous broiler litter use on residual soil fertility and crop yield.

2.) This study is not designed to study the effects of long term broiler litter use on soybean cyst nematode and whether or not new weed species are introduced into the field by litter applications.

Limitations:

1.) Limited to only making applications from one litter source per year (no comparison).

2.) Limited by the weather conditions for the 2012 through 2014 growing seasons.

3.) Limited to the plots soil type, Grenada Silt-loam with a fragipan.

4.) Study conducted under only no-till conditions.

5.) Only one soybean or corn variety per growing season will be used in this study.

Significance of the Study:

This study will help to determine how long term use of broiler litter effects residual soil fertility and crop yield, years after the last application was made. In addition it will help to determine if the residual effects of past applications of 10 and 20 pound per acre rates of copper have any influence on corn and soybean yield. The information obtained from this study will be useful to grain producers planning to use broiler litter applications in their fertility programs.

Organization of the Study:

Chapter one gave all of the background information as to why the study is being conducted as well as why it is important. Chapter two will be a review of the journal articles and educational publications related to long term effects of broiler litter use on soil properties and crop yield. Chapter three will discuss the methods that will be used to gather data and analyze the results. Chapter four will display the results of the study and chapter five will discuss the results and the conclusions gathered from them.

Chapter Summary:

Chapter one provided background into the issues and concerns that accompany long term use of broiler litter, in addition to background of the long term broiler litter study located on the Murray State Pullen farm, which is the subject of this proposal. Background into the copper study was given as well. The problems the projects are addressing and their significance were also given and the hypotheses for the studies were listed as well. Assumptions, delimitations, limitations and definition of terms were also provided in this chapter.

Chapter 2

Review of Relevant Literature

Introduction

Chapter one presented an overview of issues related to broiler litter applications as well as background into the long term broiler litter study and the copper study that developed from the broiler litter study. Statement of the problem was given and the purposes of the studies along with their significance were explained. Assumptions, delimitations, limitations, and definition of terms were also provided. Chapter two will not only review journal articles related to this research proposal, but it also includes a review of the works of two Murray State graduate students who have worked on this long term study previously.

Overview

As stated in chapter one, the research conducted was the continuation of a long term broiler litter study on the Murray State Pullen Farm that has been ongoing since 1997, as well as a copper study started in 2009. From 1997 to 2002 the plots were planted in corn with treatments of zero to seven tons of broiler litter applied per acre. Rates were cut in half in 2003 and 2004. Then in 2005 the field was plowed and no treatments were applied. Soybeans were planted from 2005 to 2007 with no litter treatments applied, however high rates of commercial phosphorus and potash were applied to the plots that previously received the one and two ton per acre litter treatments. The plots were returned to corn in 2008 and the litter treatments were again applied. Soybeans were planted on the plots from 2009 to the present, with no treatments being applied. The study is now looking at how long term annual broiler litter applications can affect residual soil fertility and crop yield.

After Upchurch (2008) saw a positive correlation between plant uptake of copper and soybean yield in 2007, Scott (2010) began a secondary study as a part from the broiler litter study to observe the effects soil applied copper at 0, 10, and 20 pound per acre rates had on yield.

Effects of Long Term Litter use on Soil Properties

When using an organic amendment such as broiler litter, especially when planning to make it part of a regular fertility plan, it is important to know how the applications will effect soil fertility long term. Broiler litter can provide 46 to 56 pounds of nitrogen per ton, 54 to 65 pounds of phosphorus (P_2O_5) per ton, and 54 to 63 pounds of potash (K_2O) per ton depending on the number of flocks that go through the house in a year’s time (Rasnake, 1996). In addition to nitrogen, phosphorus, and potash, broiler litter provides many micro and secondary nutrients (Rasnake, 1996).

Murdock and Ritchey (2012) state that animal manures contain significant amounts of the secondary nutrients calcium, magnesium, and sulfur and the micro nutrients zinc and copper. Calcium’s involvement in the formation and functioning rhizobia bacteria in legumes, its involvement in improving plant vigor and straw stiffness, promoting root and leaf development, influencing uptake of water and other nutrients, and involvement in grain and seed production are a few of calcium's roles in plant development (Mortvedt et al., 1999). Magnesium's function in plants include being an essential component of chlorophyll, regulating uptake of other nutrients, acting as a carrier for phosphorus, and aiding in the formation of sugars, proteins, oils, and fats (Mortvedt et al., 1999). Sulfur is necessary for maintaining the structural formation of enzymes, synthesis of chlorophyll, glutathione, vitamins, and some hormones, as well as the synthesis and structure of cysteine and methionine (Mortvedt et al., 1999). Copper is needed for plants to metabolize nitrogen and carbohydrates, as well as lignin synthesis (Mortvedt et al., 1999). Zinc is involved in growth regulation, energy production, and protein synthesis as a part of different enzyme systems (Mortvedt et al., 1999).

Soil test levels of nutrients, such as phosphorus, can build in the soil over time due to repeated broiler litter applications if not taken up by the crop, which has led to environmental concerns. He et al. (2008) found that total phosphorus, Mehlich 3 extractable phosphorus, and total nitrogen are influenced more so by cumulative litter applied, than years of use or annual rate. From pre plant soil samples taken in 2007, Upchurch found higher levels of soil test phosphorus and potash in plots that received historically high rates of broiler litter and commercial phosphorus and potash fertilizers than those plots receiving no or low rates of broiler litter (2008). The highest rates of soil test Zinc and Magnesium also came from plots treated with five to seven ton rates of litter over an extended number of years (Upchurch, 2008). The high levels of phosphorus and potash were not surprising in the plots treated with the higher rates of litter because the amounts of those nutrients applied were much higher than required by the crop, so the levels built in the soil over time. These nutrient levels in the soil held true even after soybean harvest, as Upchurch's post-harvest soil samples showed phosphorus and potassium levels testing highest in plots treated with higher rates of broiler litter. The micronutrients copper, zinc, and magnesium soil test levels were highest in plots treated with five to seven ton rates of litter (Upchurch, 2008). Scott's 2009 post-harvest soil sample results mirrored those of Upchurch in 2007 (Scott, 2010).

A similar study by Adeli et al. (2005) compared effects of broiler litter on soybean yield and soil nitrogen and phosphorus concentrations to commercial nitrogen and phosphorus fertilizers at equivalent rates. Adeli et al. used rates of 0, 35.72, 53.58, 71.44, and 142.88 pounds of plant available nitrogen per acre per year. When looking at residual nitrate in this study there was little to no difference in soil test levels among the control, low, and medium litter and commercial fertilizer rates. Soil nitrate levels were highest in any treatment, broiler litter or commercial fertilizer with a rate of plant available nitrogen higher than 71.44 pounds per acre (Adeli et al., 2005). This indicated that plants were able to utilize the plant available nitrogen up to the 71.44 pound level. Phosphorus built up in the soil much faster than nitrogen with the high rates of broiler litter and commercial fertilizer increasing plant available phosphorus by 71 to 77% compared to the untreated check (Adeli et al, 2005).

In a related study, Gilfillen et al. (2010) looked into how nutrient levels build in the soil due to repeated broiler litter applications over a four year period. Their study differed from others mentioned in that they based their litter treatments on plant nitrogen requirements, plant phosphorus requirements, plant phosphorus requirements plus supplemental commercial nitrogen fertilizer, and commercial fertilizers based on plant requirements for the crop being studied which was orchard grass. The litter treatments based on nitrogen requirements had the highest levels of soil test phosphorus, increasing the levels of phosphorus over four years, by three times what the levels were prior to the application of the treatments (Gilfillen et al., 2010). To meet the nitrogen requirements for orchard grass from broiler litter applications alone, much higher rates of phosphorus were applied than were required by the crop, which led to accumulation in the soil. Magnesium, copper, and zinc levels were all highest in the litter treatments based on nitrogen requirements (Gilfillen et al., 2010). The litter treatments based on nitrogen requirements provided the highest rates of litter, because as is true for most crops, nitrogen is the nutrient required in the highest amounts. For this reason, this study is in agreement with the other studies reviewed, in that phosphorus, copper, magnesium, and zinc levels build in the soil, when high rates of broiler litter are applied over several years.

In addition to build up phosphorus, copper, zinc, and magnesium Upchurch (2008), McGrath et al. (2010), and He et al. (2008) all found a trend of increased pH with poultry litter applications. Both He et al. (2008) and McGrath et al. (2010) studies agreed that it would take longer than two years to see any rise in pH. The increase in soil pH is due to broiler litter having a pH of around eight, in addition to containing calcium carbonate (McGrath et al., 2010).

Effect of Long Term Litter Use on Crop Yield

Knowing how continuous broiler litter applications effect soil properties is important, but information on its impact of yield is what growers value the most. Poultry litter has an advantage over commercial fertilizers, because in addition to nitrogen, phosphorus, and potash, it also contains micronutrients such as copper, magnesium, and zinc that can increase yield.

Upchurch (2008) saw no differences in soybean yields among treatments of broiler litter in 2007, even though the higher rates of litter (six and seven ton rates) yielded higher in 2005 and 2006. The 2007 results were due in part to a severe drought and disease pressure as a result of planting continuous soybeans for a few years (Upchurch, 2008).

Adeli et al. (2005) study showed soybean yields for plots treated with higher rates of broiler litter being higher by 10% in 2001 and 8% in 2002, than the plots treated with commercial fertilizers. The yield increase in broiler treatments over commercial fertilizers was thought to possibly be related to the micronutrients provided by the litter (Adeli et al., 2005).

Watts and Torbet (2011) examined the impact of tillage, crop rotation, and litter use on corn and soybean yield over a ten year period from 1991 to 2001. They saw broiler litter increase corn yield in three of the years evaluated and saw soybean yields increased in eight of nine years evaluated. The broiler litter was applied yearly each fall in combination with a wheat cover crop. The annual litter provided an average of 100.02 pounds of nitrogen per acre, 5.8 pounds of phosphorus per acre, 85.73 pounds of potassium per acre, 76.8 pounds of calcium per acre, and 5.8 pounds of magnesium per acre (Watts and Torbet, 2011). In addition to the poultry litter, 100.02 pounds of nitrogen as NH_4NO_3 was also applied in the fall. As a comparison, other plots were treated with equal rates of commercial fertilizer based on the nitrogen and phosphorus content of the litter. In plots where corn was planted, 50.00 pounds of nitrogen per acre was applied at planting, then an additional 100.02 pounds of nitrogen per acre in the form of NH_4NO_3 was applied as sidedress after the corn had emerged. The soybeans received no spring fertility. Watts and Torbet (2011) found corn yields were highest in tilled fields with broiler litter applied. Residual nitrogen from the litter applied to the fall cover crop benefited the following corn crop. The soybean plots that were treated with the poultry litter yielded higher than those treated with commercial fertilizers. Watts and Torbet (2011) found that poultry litter applications increased the amount of macro and micro nutrients in the soil compared to plots that only received commercial fertilzers. Like Adeli et al. (2005), Watts and Torbet (2011) credited the increased yield from broiler litter over commercial fertilizers in part to the micronutrients present in the litter.

Gilfillen et al. (2010) observed a trend that plots receiving the highest rates of litter (litter based on nitrogen requirements of the crop) had the highest yields, while those treated with litter based on phosphorus requirements had the lowest yields. The litter treatments used in this study were based on nitrogen requirements, phosphorus requirements, phosphorus requirements plus additional commercial nitrogen fertilizers, and commercial fertilizers based on requirements for orchard grass (Gilfillen et al., 2010). The treatments of commercial fertilizers and litter treatments based on phosphorus plus supplemental commercial nitrogen had similar yields. This study also supported the idea that the micronutrients gave the treatments of high rates of litter an advantage over commercial fertilizers, because as stated in the previous section the soil test values of copper, zinc, and magnesium were higher in the treatments based on crop nitrogen requirements.

Effects of Copper Applications on Plant Uptake and Crop Yield

Berger and Truog (1949) conducted an experiment applying five to ten pounds per acre of copper sulfate to soil surrounding sweet corn hills with a 200 pounds per acre rate of 3-18-9 fertilizer on six Miami silt loam field sites and one Carrington silt loam site in Wisconsin from 1940 to 1947. Although no copper deficiency symptoms were observed, the sweet corn treated with copper sulfate had a darker green appearance than the untreated corn. Applications of copper sulfate increased yields by 5% to 40% on the fields with the Miami silt loam soil type, but yield was not increased by copper applications on the Carrington silt loam site, which was much higher in organic matter (Berger and Truog, 1949).

Oplinger and Ohlrogge (1974) conducted two copper experiments in Indiana from 1967 to 1969. The first study was conducted on producer's fields where leaf tissue samples from corn and soybeans tested five ppm or less for copper. A 40 pound per acre rate of a granular mixture of copper oxide and elemental copper was broadcast onto five soybean and seven corn fields. From soybean leaf tissue samples collected the first weeks of July and August, Oplinger and Ohlrogge (1974), observed that, for the most part, significant differences in copper concentrations found in the July samples, were no longer seen by the time the August samples were collected and analyzed. Only two of the soybean plots were harvested with yields increased by 1.3% and 14.2%. Concentrations of copper in corn leaf tissue samples seemed to remain higher in the treated plots throughout the season in the first year of the study, but by the second and third year of the study, the differences in copper concentrations of the late season samples between the treated and untreated plots were not as noticeable as the July samples. Averaged across all locations corn yields were increased by 6.2%, 15.3%, and 9.1% in each of the three years of the study respectively. Oplinger and Ohlrogge (1974) observed greater yield increases due to copper applications, on sandy loams than on soils that were high in organic matter, because organic matter binds copper, which is in agreement with Berger and Truog (1949) findings.

The second study by Oplinger and Ohlrogge (1974) compared the effets of 0, 20, and 40 pound per acre rates of copper oxide (Cu_2O) and copper sulfate ($CuSO_4$ $5H_2O$) had on plant uptake and corn and soybean yield on the Purdue University Farm in 1968 and 1969. The copper sulfate applications increased soybean leaf concentrations of copper, but copper oxide did not. Soybean seed size was increased when the 20 pound per acre rate of either copper source was used. The increased seed size produced small yield increases in 1968, but made no difference the second year of the study. In 1968 neither the rate of copper or the copper source had any effect on the corn leaf sample concentrations, however yields increased as the rate of copper applied increased, regardless of the copper source. In the following year Oplinger and Ohlrogge (1974) observed that concentrations of copper were greater as the rate of copper applied increased, however in the early season leaf samples, copper concentrations were highest when copper sulfate was applied compared to copper oxide. Though the copper concentrations in the early season leaf tissue samples were higher in year two than in the first year of the study, yields were reduced as the rate of copper applied increased. Oplinger and Ohlrogge (1974) observed that greater yield reduction occurred in plots treated with copper sulfate than in those treated with copper oxide and it was suspected that the level of copper taken up by the plant may have been at a toxic level, which caused the yield in treated plots to be reduced.

According to Murdock and Ritchey (2012) there has never been a yield response to copper applications, or any reports of copper deficiencies in Kentucky. However, Upchurch (2008) observed a positive correlation between plant up take of copper and soybean yield, as plant samples taken from plots treated with six to seven tons rates of broiler litter tested the highest for copper.

Upchurch's findings lead Scott to begin a separate copper study in addition to the broiler litter study in 2009. The study compared rates of pre-plant soil applied copper at rates of 0, 10, and 20 pounds per acre. Scott (2010) saw no statistical differences in yield among the three treatments. No significant differences in plant tissue analysis copper concentrations were observed by Scott from three tissue samples taken at V5, R2, and R6. Scott (2010) did however see statistical differences in soil test copper with the 10 pounds per acre treatment having the highest value for copper and the no copper treatment having the lowest value.

Reddy et al. (1989) observed small increases in concentrations of copper from soybean leaf, stem, and grain tissue following applications of 0, 11, 22, and 44 tons per acre of sewage sludge. Soybean seed accumulated more copper than leaf or stem tissue. Concentrations of copper were highest in corn leaf tissue and increased as the rate of sludge applied increased (Reddy et al., 1989).

Summary

In review of past related research most are in agreement that long term use of broiler litter results in soil accumulation of phosphorus and micronutrients particularly copper, zinc, and magnesium. Yields are generally higher when litter is applied instead of commercial fertilizers and it is thought to be due at least in part to the micronutrients found in the litter.

A positive correlation was found between plant uptake copper and yield in 2007, but a follow up study did not support the findings in 2009. Kentucky has also generally never seen any deficiencies where copper is concerned (Murdock & Ritchey, 2012). Previous research by Berger and Truog (1949) found that copper applications increased sweet corn yield grown on a Miami silt loam soil type that was low in organic matter. Oplinger and Ohlrogge (1974) observed that copper applications increased plant uptake of copper and yield in both corn and soybean.

He et al. (2008) recommended more comprehensive research in order to quantitatively predict the impact of continuous use of broiler litter on soil properties. Most of these studies not including Upchurch (2008) and Scott (2010) have dealt only with litter applications that occur on an annual basis. The continuation of Upchurch (2008) and Scott (2010) research, which is the subject of this thesis, looked at how soil test nutrient levels and soybean yield were affected by the residual fertility remaining from litter applications made years prior to the 2012 and 2013 crops. The study also looked into how many years growers can produce from that residual fertility before another application needs to be applied.

The copper study was also continued to see if further years of data can give more insight into the relationship between copper and crop yield.

Chapter Summary

Chapter two discussed a review of several articles and publications related to broiler litter applications. Two common themes were observed from the articles reviewed. The first theme was that phosphorus, potassium, copper, zinc, and magnesium levels build in the soil when broiler litter applications are applied annually over an extended number of years. The second theme is that crop yields are generally higher when treated with higher rates of broiler litter compared to commercial fertilizers and the micronutrients provided by the litter are thought to be the difference.

Chapter two also gave a background into the long term study being continued at the Murray State Pullen Farm that was previously worked on by Upchurch (2008) and Scott (2010). The relationship between copper and crop yield was also discussed in this chapter.

Chapter 3

Methodology

Introduction

Chapter one gave background information into the issues and concerns that are associated with broiler litter applications. Background into the research projects being proposed was also given. The overall problem of determining how continuous broiler litter use effects soil properties and yield as well as continuation of the copper study was stated in chapter one. Hypotheses were included, as well as, the assumptions for the study and the delimitations and limitations of the study.

Chapter two gave a review of several research articles and educational publications related to broiler litter applications. The research methods used to conduct their studies were examined and the results of the studies were examined to find common themes.

Chapter three will describe the research methods in regards to design, data collection, and data analysis.

Rationale

A randomized complete block was the design used for this study to eliminate any influence of plot location within in the study. It is also appropriate, because the study is a long term project that has been located in the same place since 1997.

Context of the study

The study took place at the Murray State University Pullen Farm, where the study has been located since 1997. This thesis project was the continuation of a long term study and since the study deals with residual soil fertility, it was necessary for the plot to remain in the same place.

Data source

2012

The plot dimensions for both the broiler litter and copper studies were 17.4 feet long by 15 feet wide and both studies have four replications. The soil type for the location of both studies on the Pullen Farm is a Grenada Silt Loam. In 2012 Asgrow 4832 soybeans were planted on May 24th. No treatments of broiler litter or copper were applied to the studies in 2012. A burndown of a premix herbicide of 0.117 pounds of sulfentrazone active ingredient per acre (ai/acre) plus 0.024 pounds of chlorimuron ai/acre, a premix herbicide of 0.058 pounds of salflufenacil ai/acre plus 0.508 pounds of dimethenamid ai/acre, 1.5 pounds of glyphosate isopropylamine salt ai/acre, and 1% v/v methylated seed oil was applied on May 16th. The premix of 0.058 pounds of salflufenacil ai/acre plus 0.508 pounds of dimethenamid ai/acre was higher than the normal rate of 0.022 pounds of salflufenacil ai/acre plus 0.195 pounds of dimethenamid ai/acre. On July 18th, a post-emergent herbicide of 1 pound of glyphosate isopropylamine salt ai/acre, combined with a fungicide application of 0.1 pounds pyraclostrobin ai/acre and 0.125% v/v of nonionic surfactant was applied to both the broiler litter and copper studies. According to Kentucky Mesonet monthly summaries, the average temperatures for the months of May, June, July, August, September, and October in 2012 were 71.4, 75.5, 82.8, 77.1, 68.7, and 57.1 degrees Fahrenheit (^{o}F) respectively (Kentucky Mesonet, 2012). A total of 21.19 inches of rain fell during the 2012 growing season, with 4.17 inches coming in July (Kentucky Mesonet, 2012). The broiler litter and copper studies were harvested on November 1st and 2nd.

2013

In 2013 both the broiler litter and copper studies were again planted to soybeans. No litter or copper was applied to either study. On May 15th a premix herbicide of 0.079 pounds of sulfentrazone ai/acre plus 0.009 pounds of carfentrazone ai/acre, 0.053 pounds of pyroxasulfone ai/acre, 0.294 pounds of glyphosate isopropylamine salt ai/acre, and NIS at 0.1% v/v was applied pre-plant to both the broiler litter and copper studies. Then on May 20th both studies received herbicide applications of a premix of 0.022 pounds of salflufenacil ai/acre plus 0.195 pounds of dimethenamid ai/acre, 0.663 pounds of glyphosate isopropylamine salt ai/acre, a premix of 0.023 pounds imazethapyr ai/acre plus 0.266 pounds of glyphosate isopropylamine salt ai/acre, methylated seed oil at 0.5% v/v, and UAN at 0.5% v/v. Both studies were planted on June 4th with Pioneer 94Y70 soybeans. An herbicide application of 1.375 pounds of glyphosate potassium salt ai/acre, 0.25% v/v of nonionic surfactant, and 5% w/v of dry AMS was applied to both studies, as well as some nearby corn on June 28th. Due to the June 28th herbicide application also being applied to corn, a second herbicide application of 0.016 pounds of cloransulam ai/acre, 0.25% v/v of nonionic surfactant, and 2.5% v/v of UAN was applied on June 29th. The first three replications of the broiler litter study were harvested on October 18th and the fourth replication and copper study were harvested on October 22nd. The average monthly temperatures for June, July, August, September, and October were 75, 74.8, 75.3, 70.8, and 59.5 degrees ^{o}F (Kentucky Mesonet, 2013). From June 4th to October 22, 2013, the Kentucky Mesonet station in Calloway County reported 24.7 inches of rainfall (Kentucky Mesonet, 2013). The soybeans for both the broiler litter and copper studies were harvested October 18^{th} and 22^{nd}, during which time it rained 0.23 inches (Kentucky Mesonet, 2013).

2014

During the 2014 growing season both studies were returned to corn. Both the broiler litter and copper studies received an early pre-plant herbicide application of a premix of 0.045 pounds of saflufenacil ai/acre plus 0.391 pounds of dimethenamid ai/acre, 0.902 pounds of glyphosate potassium salt ai/acre. On May 17^{th} a second pre-plant herbicide application of a premix of 0.544 pounds of s-metolachlor ai/acre plus 0.070 pounds of mesotrione ai/acre plus 0.544 pounds of atrazine ai/acre, 0.883 pounds of atrazine ai/acre, 0.731 pounds of s-metolachlor ai/acre, and 1% v/v crop oil concentrate was applied to both the broiler litter and copper studies. A pre-plant application of 180 pounds per acre of nitrogen from 32% UAN was applied to the copper study only using a sidedress style applicator. On May 19^{th} both the broiler litter and copper studies were planted with Armor 1330 Pro2. Treatments of 0 to 7 tons per acre of broiler litter were applied to the broiler litter study on June 7^{th}; however no treatments were applied to the copper study. Both the broiler litter and copper studies received a post emergence herbicide application of 1.203 pounds of glyphosate potassium salt ai/acre and 0.2 % v/v nonionic surfactant on June 25^{th}. Both studies were hand harvested on September 27^{th}. The average daily temperatures for the months of May, June, July, August, and September were 68.5, 75.4, 72.6, 78.3, and 69.5 ^{o}F respectively (Kentucky Mesonet, 2014). August was the warmest month with eleven straight days from the 19^{th}

to the 29th having temperatures of 90 ^{o}F or higher (Kentucky Mesonet, 2014). The 2014 growing season was the driest of the three years with only 17.47 inches of rainfall (Kentucky Mesonet, 2014). The month of July was the driest with only 0.9 inches (Kentucky Mesonet, 2014).

Data collection methods

This research was conducted over three years with the plots planted in soybeans the first two years and corn in the third year.

2012

During the 2012 growing season only yield data was collected from both the broiler litter and copper studies to determine if yield was affected by treatments of copper or broiler litter from previous years. On November 1st and 2nd both the broiler litter and copper studies were harvested. Two uniform rows from each plot were cut down using hand pruners, wrapped in a cloth with an index card that contained the plot number, and then carried to a stationery thresher. The threshed seed and remaining pod and stem debris were collected in a bag, along with the index card containing the plot number, and were stored in a lab. The seed was later cleaned in the lab, using a series of sieves to remove the pods and stems. On February 9th the soybeans were weighed and moistures were recorded.

2013

In 2013 multiple data collections were made from both the broiler litter and copper studies. Soil samples were pulled from every individual plot from both the broiler litter and copper studies. Five cores were taken from each plot at a depth of 4 inches, because the field was in a no-till system. The samples from the broiler litter study, along with an additional composite to test for soybean cyst nematode, were pulled on June 8, 2013. The samples from the copper study were taken on October 26th. The soil samples from both studies were sent to the University of Kentucky's soil testing lab in Lexington and the SCN sample was tested at the University of Kentucky's SCN lab in Princeton. On June 22nd, stand counts per five feet of row from four rows were taken at growth stage V1 to V2. Twenty-five trifoliate leaves were pulled from each plot of both studies on July 18th, when the soybeans were at growth stage R1, but were lost in the mail in route to Waters Lab. Tissue samples were pulled again on August 24th, at growth stage R5; in the same manner the R1 samples were pulled. The samples were dried in the lab prior to being sent to Waters Lab for analysis. The soybeans in the broiler litter study were tall in 2013 which led to lodging. On September 7th the heights of five plants per plot were measured free standing from their tallest point and lodging ratings from 0 to 100% were also recorded for each plot. The first three reps of the broiler litter study were harvested on October 18th by cutting down two rows of soybeans with hand pruners, wrapping them in a cloth with a note card identifying the plot number, and running the plants through a stationary thresher, and the seed was then bagged and stored in the crops lab. The fourth rep of the broiler study and all four reps of the copper study were harvested on October 22nd in the same manner. During January and February of 2014 the seeds were screened to remove the pods and stem fragments, not removed by the stationary thresher. The clean seed was weighed and moisture samples were recorded on February 15th.

2014

Just as in 2013, multiple data collections were also taken from the corn in 2014. On June 7th, the number of plants in 10 ft. of row was counted from 4 rows from each plot, in both the broiler litter and copper studies. A sample of the broiler litter that was applied on June 7th was collected and sent to Waters Lab for analysis on December 5th. The heights in inches of 5 plants from each plot of both the broiler litter and copper studies were measured on July 6th. Tissue samples were collected at tasseling on July 19th, by collecting 10 ear leaves from one row of each plot from both the broiler litter and copper studies. In plot 21, only 6 plants were mature enough from which to collect an ear leaf. The row, from which the tissue samples were pulled, was marked with a plot stake, so that it would not be used for a harvest row. The samples were dried in the soils lab and sent to Waters Lab for analysis. Leaf temperature readings were collected from the broiler litter study on two separate dates to determine if increased organic matter from broiler litter treatments increased the water holding capacity of the soil, which would reflect a difference in leaf temperatures among treatments. The first leaf temperature readings were taken on July 19th. The leaf temperature of ten ear-leaves per plot were measured with an Extech 30" Dual Laser IR Thermometer (Extech Instruments Corporation, Waltham,MA). The second leaf temperature readings were collected on August 23rd, however due to the warm dry conditions the leaves had begun to dry up so the measurements were taken two leaves above the ear which was the lowest green leaf left on the plants. One row from each plot of both the broiler litter and copper studies was hand harvested on September 27th. Two ears from each plot were weighed at field moisture and then placed in a drier. On September 29th and 30th photos of the corn ears were taken and the number of ears from each plot were counted. The dry ear weights of the two corn ears that were placed in the drier for a moisture sample were then recorded and the weights for the entire row harvested were also recorded. Soil samples were pulled from each plot of both the broiler litter and copper studies on December 13th and were sent to the University of Kentucky's soil lab in Lexington.

Data analysis

Statistics were ran using the SAS program (SAS Institute, 2008). Analysis of variance (ANOVA) was used on each source of data collected to determine if there were any significant differences among treatments.

Chapter Summary

Chapter three was a review of what research design was used, what types of data were collected, how it was collected, and how data was analyzed. The research design of this study is a randomized complete block. Data collected consisted of analysis of soil samples, stand counts, analysis of plant tissue samples, plant heights, lodging ratings, leaf temperature readings, corn ear counts and yield. Analysis of Variance was used to find statistical differences among eight treatments of broiler litter and three treatments of copper.

Chapter 4

Results

Introduction

Chapter three explained the research design of the study, what data was collected and the collection procedures, and how the data was analyzed. Chapter four will present the data collected. The results presented in this chapter will include soil sample results for the 2013 and 2014 growing seasons, plant tissue analysis from both the 2013 and 2014 growing seasons, soybean plot yields from 2012 and 2013, and corn plot yields from the 2014 growing season for both the broiler litter and copper studies.

Results for Objective 1

Broiler litters effect on soil test levels, plant tissue test levels, and yield was the main focus of objective one. Table 1 displays the mean primary soil nutrient values for the broiler litter study in 2013. Mean soil test pH values ranged from 6.36 in the one ton per acre broiler litter treatment to 6.77 in the seven tons per acre treatment. There was no statistical difference in soil pH among the seven, six, and five tons per acre broiler litter treatments, but the pH level for the seven tons per acre treatment was statistically higher than in the plots treated with the zero through four tons rates. Plots treated with the six tons per acre rate of broiler litter had significantly higher mean pH values than did those treated with the zero, one, two, and four tons per acre rates of litter. The mean pH value for plots treated with the five tons per acre rate of broiler litter was significantly higher than the plots receiving the one and four tons per acre treatment. There was also no statistical difference in mean soil test pH values among the plots treated with the three, five, and six tons of litter per acre rates or among those treated with the four, two, one, and zero ton per acre rates.

Table 1
2013 Mean Soil Test Values for Primary Nutrients Plus pH and Organic Matter

Treatment (Tons/Acre)	pH	OM (%)	Total N (%)	P (lbs/ac)	K (lbs/ac)
7	6.77 a	2.29 abc	0.1460 abc	159.50 a	281.50 a
6	6.72 ab	2.38 a	0.1518 a	115.50 bc	257.50 ab
5	6.61 abc	2.31 ab	0.1515 ab	103.75 cd	207.75 c
4	6.42 de	2.27 abc	0.1500 ab	74.75 e	196.25 cd
3	6.55 bcd	2.05 de	0.1355 d	45.50 f	156.25 d
2**	6.51 cde	2.10 cd	0.1375 cd	125.75 b	239.00 abc
1**	6.36 e	2.16 bcd	0.1413 bcd	97.00 d	232.50 bc
0	6.54 cde	1.87 e	0.1218 e	23.50 g	159.75 d
Pr > F	0.0111	0.0022	0.0008	<0.0001	0.0007
LSD (P = 0.1)	0.18	0.18	0.01	17.19	45.04

Note. Values with a common letter are not statistically different.
** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

Mean soil test organic matter ranged from 1.87 percent (%) in the no broiler litter treatment to 2.38% in the six tons per acre treatment. The mean soil test organic matter was significantly higher in the plots treated with the six tons per acre rate of broiler litter compared to those treated with the zero through three tons per acre rates. Plots treated with the five tons per acre rate of broiler litter had a significantly higher mean soil organic matter level than did those treated with the zero, two, and three tons per acre rates. Significantly higher levels of soil organic matter were also observed in plots treated with the seven, four, two, and one tons per acre rates of broiler litter than in those receiving the no litter treatment. No significant difference in organic matter was seen among the seven, six, five, and four tons per acre rates and no significant difference was seen among the three, two, and one tons per acre rates. The plots treated with the three tons per acre rate of litter did not have a statistically higher percentage of soil organic matter than the plots receiving no litter.

Mean values for soil test nitrogen ranged from 0.1218% in plots receiving no litter to 0.1518% in plots treated with the six tons per acre rate of broiler litter. Soil test total nitrogen was significantly higher in plots receiving six, five, and four tons of litter per acre compared to those receiving rates of three, two, and zero tons of litter. The plots treated with the six tons per acre rate of broiler litter also had a significantly higher value for total nitrogen than the plots treated with the one ton rate. Plots receiving no litter had significantly lower levels of soil test total nitrogen than did the plots receiving any amount of litter. The mean total nitrogen value for the plots receiving the seven tons per acre rate of broiler litter was significantly higher than for the plots receiving the three tons per acre rate. No significant differences in soil test total nitrogen were seen among plots receiving four, five, six, and seven tons of litter per acre; one, four, five and seven tons of litter per acre; two and three tons of litter per acre; or one, two, and seven tons of litter per acre.

Mean soil test phosphorus values ranged from 23.5 pounds per acre (lbs/A) in the no broiler litter treatment to 159.5 lbs/A in the seven tons per acre treatment. The plots receiving the seven tons per acre rate of litter had a statistically higher level of soil test phosphorus than all the other treatments and the plots receiving no litter had a statically lower level of soil test phosphorus than all the plots that received litter. The mean soil test phosphorus values for the plots treated with the two tons per acre rate of broiler litter was significantly higher than any other treatment except the six and seven ton rates of broiler litter. In 2005, 2006, and 2009; 230 lbs/A of inorganic phosphorus (P_2O_5) and 250 lbs/A of inorganic potassium (K_2O) were applied to the plots historically treated with the one and two tons per acre rates of broiler litter. Plots treated with the six tons per acre rate of broiler litter had a significantly higher value for mean soil test phosphorus than plots receiving the one, three and four tons per acre treatments. Mean soil test values for phosphorus were significantly higher in plots receiving the five tons per acre rate of broiler litter than those receiving the three and four tons per acre rates. Mean phosphorus values were greater for plots treated with the one ton per acre treatment of litter than in the plots treated with the three and four tons rates. Also the plots treated with the four tons rate of litter had a significantly higher mean value for soil test phosphorus than did the three tons rate. There was no significant difference in mean soil test phosphorus values between the treatments of one and five tons per acre rates of broiler litter; the two and six tons per acre rates; or between the five and six tons rates.

The mean soil test values for potassium ranged from 159.75 lbs/A in the no litter treatment to 281.5 lbs/A in the plots receiving the seven tons per acre treatment of broiler litter. The mean soil test potassium values were significantly higher for the plots treated with the six and seven tons per acre rate of litter than those treated with the five, four, three, and zero tons rates. Plots treated with the one, two, and five tons per acre rates of broiler litter had statistically higher values for soil test potassium than did the zero, and three tons per acre rates. No significant differences in soil test potassium were seen among the plots treated with the seven, six, and two tons per acre rates; the one, two, four, and five tons per acre rates; or the zero, three, and four ton per acre rates.

The mean secondary and micro nutrient data for 2013 is presented in Table 2. Mean values for soil test calcium ranged from 2742.8 lbs/A in plots treated with no broiler litter to 3359.8 lbs/A in the plots receiving the five tons per acre rate of litter. There was no statistical difference in soil test calcium from the one to seven tons per acre rates; however there was a significant difference between the plots treated with litter and those receiving no litter.

Table 2

2013 Mean Soil Test Values for Secondary and Micro Nutrients

Treatment (Tons/Acre)	Ca (lbs/ac)	Mg (lbs/ac)	Zn (lbs/ac)	B (lbs/ac	Cu (lbs/ac)	Mn (lbs/ac)	Fe (lbs/ac)
7	3329.5 a	468.0 ab	14.8 a	1.1 a	17.5 a	573.5 abc	308.0 ab
6	3305.3 a	465.5 ab	12.1 b	0.9 b	14.3 b	562.0 abc	304.0 ab
5	3359.8 a	482.0 a	11.5 b	1.0 ab	14.3 b	486.5 cd	320.0 a
4	3296.3 a	460.0 ab	9.2 c	0.9 bc	12.4 c	452.0 d	318.5 a
3	3088.0 a	405.3 cd	6.7 d	0.9 b	8.7 d	590.0 ab	278.5 bc
2	3133.3 a	410.0 c	6.4 d	0.9 bc	7.7 d	580.5 abc	313.5 a
1	3208.3 a	433.5 bc	4.9 e	0.8 c	5.7 e	496.5 bcd	309.0 a
0	2742.8 b	369.3 d	4.2 e	0.8 c	4.2 f	619.5 a	266.0 c
Pr > F	0.0470	0.0004	<0.0001	0.0041	<0.0001	0.0763	0.0462
LSD (P=0.1)	309.5	37.8	1.2	0.1	1.2	96.7	29.8

Note. Values with a common letter are not statistically different.

Mean soil test magnesium values ranged from 369.3 lbs/A in the no litter treatment to 482.0 lbs/A in the plots treated with the five tons per acre rate of broiler litter. No significant difference in soil test magnesium was observed among plots treated with the four, five, six, and seven tons per acre litter rates. Soil test magnesium was significantly higher in plots treated with the five tons per acre rate of litter compared to the plots that had received the zero, one, two, and three tons per acre rates. The plots receiving historical rates of four, six, and seven tons per acre rates of litter had significantly higher levels of magnesium than plots receiving the zero, two, and three tons rates. The only plots receiving broiler litter that did not have a statistically higher mean value for soil test magnesium than plots receiving no litter, were the plots treated with the three tons per acre rate of broiler litter.

Mean values for soil test zinc ranged from 4.2 lbs/A in the no litter treatment to 14.8 lbs/A in the plots treated with the seven tons per acre rate of broiler litter. Mean soil test values for zinc were significantly higher in the plots treated with seven tons per acre of litter compared to all other treatments. There was no significant difference in soil test zinc between the plots treated with the five and six tons per acre rates, but those plots had higher values than any of the plots treated with lower rates of litter. The level of soil test zinc was significantly higher in the plots receiving the four tons per acre rate of broiler litter than the plots receiving the three, two, one, and zero tons per acre rates. No significant difference was observed in mean soil test zinc values between the two and three tons per acre rates of broiler litter, but both were statistically higher than the zero and one ton per acre rates. There was no statistical difference in soil test zinc between the zero and one ton per acre rates.

Mean values for soil test boron ranged from 0.8 lbs/A in plots treated with both the zero and one ton per acre rates of broiler litter to 1.1 lbs/A in the plots receiving the seven tons per acre rate of broiler litter. Soil test boron was significantly higher in plots treated with the seven tons per acre rate of broiler litter compared to any other treatment with the exception of the five tons per acre rate, for which no statistical difference was observed. Plots treated with the three, five, and six tons per acre rates of broiler litter had statistically higher mean soil test boron values than did the plots treated with the zero and one ton per acre rates. No significant difference in soil test boron was observed among plots treated with the six, five, four, three, and two tons per acre rates of broiler or among those treated with the zero, one, two, and four tons per acre rates.

Mean values for soil test copper ranged from 4.2 lbs/A in the plots receiving the no litter treatment to 17.5 lbs/A in the plots treated with the seven tons per acre rate. The level of soil test copper was statistically highest in the plots treated with the seven tons per acre rate of litter and lowest in the plots receiving no litter. The mean soil test copper values declined steadily as the rate of broiler litter applied was reduced with no significant difference being seen between the five and six tons per acre rates and the two and three tons per acre rates.

Mean soil test manganese values ranged from 452.0 lbs/A in the plots treated with the four tons per acre rate of broiler litter to 619.5 lbs/A in the plots treated with no litter. Mean values for soil test manganese were significantly higher in the plots treated with no litter than in the plots treated with the one, four, and five tons per acre rates. Plots treated with the two, three, six, and seven tons per acre rates of broiler litter had significantly higher values for mean soil test manganese than plots treated with the four tons per acre rate. The plots treated with the three tons per acre rate of broiler litter also had a significantly higher value for mean soil test manganese than did the plots treated with five tons per acre rate. No significant differences in soil test manganese were observed among the plots treated with the zero, two, three, six and seven tons per acre rates of broiler litter; the one, two, five, six, and seven tons per acre rates; or among the one, four, and five tons per acre rates of broiler litter.

Mean soil test iron values ranged from 266.0 lbs/A in the plots receiving no litter to 320.0 lbs/A in the plots treated with the five tons per acre rate of broiler litter. No significant difference was seen in soil test iron among plots treated with the one, two, four, five, six, and seven tons per acre rates of broiler litter. Plots treated with the three tons per acre rate of broiler litter were not significantly different in soil test iron from the six and seven tons per acre rates, but also were not significantly different from the plots receiving no litter. Plots receiving the no broiler litter treatment had a statistically lower value for soil test iron than all the other treatments except the three tons per acre rate.

The mean primary soil test nutrient values for the 2014 broiler litter study are presented in Table 3. These samples reflect soil test nutrients following the 2014 corn crop and the applications of broiler litter made that spring. Mean soil test pH values ranged from 6.32 in plots treated with the one ton per acre rate of broiler litter to 6.72 in the plots receiving the seven ton per acre rate. Mean values for soil test pH were significantly higher in plots receiving the seven, six, and three tons per acre rates of broiler litter than for the plots receiving the two and one tons per acre rates. Plots treated with the seven tons per acre rate of broiler litter also had a statistically higher mean soil test pH value than the plots treated with the four tons rate. The mean soil pH values were also significantly higher in plots receiving the zero, four, and five tons per acre rates compared to the plots receiving the one ton per acre rate of broiler litter. No significant differences in soil pH were seen between plots treated with the zero, three, five, six, and seven tons per acre rates of broiler litter; the zero, three, four, five, and six tons per acre rates, or between the one and two tons per acre rates.

Table 3

2014 Mean Soil Test Values for Primary Nutrients Plus pH and Organic Matter

Treatment (Tons/Acre)	pH	OM (%)	Total N (%)	P (lbs/ac)	K (lbs/ac)
7	6.72 a	2.63 a	0.17 a	261.50 a	375.75 a
6	6.71 ab	2.63 a	0.18 a	165.50 b	256.25 b
5	6.61 abc	2.66 a	0.17 a	140.25 bc	241.50 bc
4	6.53 bc	2.27 b	0.16 b	85.75 cd	190.25 de
3	6.66 ab	2.17 b	0.14 b	65.75 de	181/75 de
2**	6.46 cd	2.33 b	0.16 b	139.75 bc	204.00 cd
1**	6.32 d	2.40 ab	0.16 ab	97.50 cd	183.50 de
0	6.59 abc	1.82 c	0.12 c	21.00 e	148.50 e
Pr > F	0.0034	<0.0001	<0.0001	<0.0001	<0.0001
LSD (P = 0.05)	0.19	0.30	0.02	55.40	43.50

Note. Values with a common letter are not statistically different.

** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

Mean values for soil test organic matter ranged from 1.82% in plots that were treated with no broiler litter to 2.66% in plots treated with the five tons per acre rate of broiler litter. Soil test organic matter was significantly lower in the plots receiving no litter compared to plots treated with any rate of litter. Plots treated with the seven, six, and five tons per acre rates of broiler litter had significantly higher levels of organic matter than the plots receiving the four, three, and two tons per acre rates. No significant differences were observed among the plots treated with seven, six, five, and one tons per acre rates of broiler litter or among those treated with the one, two, three, and four tons rates.

The mean values for total nitrogen ranged from 0.12% in the plots receiving no litter to 0.18% in the plots treated with the six tons per acre rate of broiler litter. Mean values for soil test total nitrogen were significantly lower in plots treated with the two, three, and four tons per acre rates of litter than in the plots that received the seven, six, and five tons per acre rates. Plots that received any rate of litter at all had a significantly higher mean value for soil test total nitrogen than did the plots receiving the no litter treatment. No significant differences in soil test total nitrogen were observed among plots treated with the seven, six, five, and one tons per acre rates of broiler litter or among those treated with the one, two, three, and four tons per acre rates.

Mean soil test phosphorus values ranged from 21.0 lbs/A in plots receiving the no broiler litter treatment to 261.5 lbs/A in plots treated with the seven tons per acre rate. A significantly higher value for mean soil test phosphorus was observed in plots receiving the seven tons per acre rate of broiler litter than in any of the plots treated with the lower rates. The plots treated with the six tons per acre rate of broiler litter were significantly higher in soil test phosphorus than plots receiving the zero, one, three, and four tons per acre rates. Plots receiving the one, two, four, and five tons rates of litter had significantly higher mean soil test phosphorus values than plots that were not treated with broiler litter. The plots treated with the two and five tons per acre rates of broiler litter also had significantly higher mean values for soil test phosphorus than plots receiving the three tons per acre treatment. No significant differences were observed among plots treated with the two, five, and six tons per acre rates of broiler litter; the one, two, four, and five tons rates; or between the zero and three tons per acre treatments.

Mean soil test potassium values ranged from 148.50 lbs/A in plots receiving the no broiler litter treatment to 375.75 lbs/A in the plots treated with the seven tons per acre rate. Soil test potassium was significantly higher in plots treated with the seven tons per acre rate of broiler litter than in plots receiving any lower rate. Plots receiving the six tons per acre rate of litter had significantly higher mean values for soil test potassium than those receiving any lower rate of litter, with the exception of the plots treated with five tons per acre rate, which was not significantly different. The plots treated with the five tons per acre rate of litter had significantly higher mean soil test potassium values than plots treated with any of the lower rates of broiler litter, with the exception of the plots receiving the two tons per acre rate of litter which was not significantly different. Plots treated with the two tons per acre rate of litter had significantly higher mean values for potassium than the plots received no litter. No significant differences in mean soil test potassium were observed among plots treated with the one through four tons per acre rates of broiler litter or among the zero, one, three, and four tons per acre rates.

The mean secondary and micro nutrient soil test values for the 2014 growing season are displayed in Table 4. Mean values for soil test calcium ranged from 2671.3 lbs/A in the no litter treatment to 3326.3 lbs/A in the seven tons per acre treatment. No significant difference in soil test calcium was observed among the broiler litter treatments.

Table 4
2014 Mean Soil Test Values for Secondary and Micro Nutrients

Treatment (Tons/Acre)	Ca (lbs/ac)	Mg (lbs/ac)	Zn (lbs/ac)	Cu (lbs/ac)	Mn (lbs/ac)	Fe (lb/ac)
7	3326.3	548.3 a	20.9 a	19.6 a	512.0 abc	155.5
6	3122.5	499.0 ab	15.0 b	16.2 b	484.0 abc	150.3
5	3282.8	515.5 ab	13.6 b	13.7 c	461.5 bc	154.5
4	3057.5	465.5 bc	9.3 c	10.9 d	418.5 c	148.0
3	3083.8	455.3 bc	8.9 c	9.4 de	549.0 ab	137.8
2	2955.0	411.3 cd	7.9 cd	7.8 ef	519.0 ab	153.8
1	3006.3	424.5 cd	5.6 de	6.1 fg	416.5 c	151.8
0	2671.3	377.8 d	4.2 e	3.9 g	565.5 a	133.8
Pr > F	0.1003	0.0007	<0.0001	<0.0001	0.0353	0.1320
LSD (P =0.05)	NS	69.3	2.7	2.1	99.6	NS

Note. Values with a common letter are not statistically different.

Mean values for soil test magnesium ranged from 377.8 lbs/A in the no litter treatment to 548.3 lbs/A in the seven tons per acre treatment. The plots treated with the seven tons per acre rate of litter had significantly higher mean values for soil test magnesium than the plots receiving the zero, one, two, three, and four tons rates. Plots treated with no litter were also significantly lower in magnesium than plots treated with the three, four, five, and six tons per acre rates of broiler litter. Plots treated with the five and six tons per acre rates of broiler litter had statistically higher mean values for soil test magnesium than zero through two tons per acre rates of litter. No significant differences in soil test magnesium were seen among plots treated with the seven, six, and five tons rates; the three, four, five, and six tons rates; the one, two, three, and four tons rates; or the zero, one, and two tons per acre rates of broiler litter.

The no broiler litter treatment had the lowest mean value for soil test zinc at 4.2 lbs/A, while the highest mean value for zinc was seen in the seven tons per acre treatment at 20.9 lbs/A. Mean soil test values for zinc were significantly higher in the plots treated with the seven tons per acre rate of broiler litter than in any of the plots receiving a lower rate. There was no significant difference in mean soil test zinc values between plots receiving the five and six tons per acre rates of litter, but the value for zinc in those plots was statistically higher than in the plots treated with any of the lower rates of litter. No significant difference in mean soil test zinc values were observed among plots treated with the two, three, and four tons per acre rates of broiler litter, however the zinc values for those plots were all significantly higher than in those that received the no litter treatment. The plots treated with the three and four tons per acre rate of broiler litter also had significantly higher mean values for soil test zinc than the plots treated with the one ton per acre rate. There was also no significant difference in soil test zinc observed between the one and two tons per acre rates of litter or between the zero and one tons per acre rates.

Mean soil test copper values ranged from 3.9 lbs/A in the no litter treatment to 19.6 lbs/A in the plots treated with the seven tons per acre rate. Mean values for copper were significantly higher in the seven tons per acre broiler litter treatment than in any of the treatments at lower rates of broiler litter. The plots treated with the six tons per acre rate of broiler litter had statistically higher values for soil test copper than the plots treated with the five tons per acre rate, but both treatments had significantly higher values for copper than any of the lower rate treatments. Mean values for soil test copper were significantly higher in the four tons per acre broiler litter treatment than in the zero to two tons per acre rates, while the three tons per acre treatment had statistically higher values than the one ton and no litter treatments. The only treatment that did not have a statistically higher mean value for soil test copper than the no litter treatment was the one ton per acre rate of broiler litter which was not significantly different. No significant differences in mean values for soil test copper were observed among the plots treated with the three and four tons per acre rates of broiler litter, the two and three tons per acre rates, the one and two tons per acre rates, and the no litter and one ton per acre rates.

The mean values for soil test manganese ranged from 416.5 lbs/A in the one ton per acre treatment to 565.5 lbs/A in the no litter treatment. Soil test manganese was significantly higher in plots treated with no litter compared to those treated with the one, four, and five tons per acre rates. Plots receiving the treatments of two and three tons of broiler litter per acre had significantly higher mean values for soil test manganese than did those treated with the one and four tons per acre rates. No significant differences in mean soil test manganese values were observed among the zero, two, three, six and seven tons per acre rates of broiler litter; the two, three, five, six, and seven tons per acre rates; or among the one, four, five, six, and seven tons per acre rates.

Mean values for soil test iron ranged from 133.8 lbs/A in the no litter treatment to 155.5 lbs/A in the seven ton per acre treatment of broiler litter. No statistical difference in soil test iron values were observed among any of the treatments.

In addition to the effect that long term broiler litter use had on soil nutrient values, objective one also observed the levels of nutrients taken up by the crop through plant tissue analysis. The mean plant tissue analysis results from 2013 reflect the amount of nutrients observed in the soybean plants at the R5 growth stage. The mean values of macro nutrients from plant tissue analysis are displayed Table 5. No treatments of broiler litter were applied to the soybeans in 2013.

Table 5
2013 Mean R5 Soybean Plant Tissue Analysis Values for Macro Nutrients

Treatment (Tons/Acre)	N %	P %	K %	Mg %	Ca %	S %
7	4.768	0.303 b	1.288	0.345	1.520	0.260
6	4.770	0.313 ab	1.193	0.405	1.540	0.250
5	4.598	0.318 ab	1.070	0.433	1.538	0.265
4	4.963	0.318 ab	1.035	0.473	1.600	0.268
3	4.818	0.320 a	1.000	0.503	1.530	0.263
2**	4.778	0.313 ab	1.063	0.433	1.583	0.260
1**	4.845	0.315 ab	1.153	0.423	1.618	0.260
0	4.925	0.278 c	1.075	0.420	1.425	0.258
Pr > F	0.9167	0.0072	0.2748	0.1788	0.1727	0.6731
LSD (P = 0.1)	NS	0.017	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.
** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

Plant tissue analysis mean values for nitrogen ranged from 4.598% from plants treated with the five tons of broiler litter per acre rate to 4.963% from plants treated with the four tons per acre rate. There was no statistical difference in plant tissue analysis nitrogen values among any of the treatments.

The mean values for plant tissue analysis phosphorus ranged from 0.278% in the no broiler litter treatment to 0.32% in the three tons per acre treatment. The plants from plots receiving no litter had significantly lower mean values for phosphorus than samples taken from plots that received any rate of litter. The mean value for plant tissue analysis phosphorus was significantly higher in samples taken from the plots receiving the three tons per acre rate of litter than in the plots treated with the seven tons rate. No significant differences were seen in phosphorus values among the one through six tons per acre rates or among the one, two, four, five, six, and seven tons per acre rates of broiler litter.

Mean plant tissue analysis potassium values ranged from 1.000% in the plots receiving the past rates of three tons of broiler litter per acre to 1.288% from those that received the seven tons per acre rate. There were no significant differences in plant tissue analysis potassium observed among the broiler litter treatments.

Mean values for plant tissue analysis magnesium ranged from 0.345% in samples taken from the plots treated with the seven ton per acre rate of broiler litter to 0.503% from those treated with the three ton per acre rate of litter. No significant differences in plant uptake of magnesium were observed among the treatments.

Mean values for calcium from plant tissue analysis ranged from 1.425% in the samples collected from plots treated with no broiler litter to 1.618% in samples collected from plots treated with the one ton per acre rate. No significant differences in calcium concentrations were observed among the treatments from the R5 soybean leaf tissue analysis.

Mean values for sulfur from plant tissue analysis ranged from 0.25% in plots receiving the six tons per acre rate of broiler litter to 0.268% in plots treated with the four tons per acre rate. R5 soybean leaf tissue analysis showed no statistical differences in plant uptake of sulfur among the broiler litter treatments.

The mean values of micro nutrients from plant tissue analysis from the 2013 soybean growing season are displayed in Table 6. Mean values for boron from plant tissue analysis ranged from 43.75 ppm in plots treated with the seven tons per acre rate of broiler litter to 55.75 ppm from plots receiving the four tons per acre treatment. Mean boron values from plots treated with the three and four tons per acre rates of litter were significantly higher than in the plots receiving the six and seven tons per acre rates. Plots receiving no litter had significantly higher values for boron than the plots treated with the seven tons per acre rate of litter. No significant differences in mean born values were observed among plots treated with the zero through five tons per acre rates of broiler litter; the zero, one, two, five, and six tons per acre rates; or among the one, two, six, and seven tons per acre rates.

Mean zinc values from plant tissue analysis ranged from 32.75 ppm in the two tons per acre broiler litter treatment to 39.5 ppm in the five tons per acre treatment. Plant tissue analysis values for manganese ranged from 94.75 ppm from samples collected from plots that were treated with no broiler litter to 107.75 ppm in the two tons per acre treatment. The mean values for iron from plant tissue analysis ranged from 72.75 ppm in the no litter treatment to 114 ppm in the six tons per acre treatment of broiler litter. No statistical differences in plant uptake of zinc, manganese, or iron were observed among the litter treatments.

Table 6

2013 Mean R5 Soybean Plant Tissue Analysis Values for Micro Nutrients

Treatment (Tons/Acre)	B ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm
7	43.750 c	33.750	103.500	85.25	7.00 d
6	47.500 bc	35.500	96.000	114.00	7.50 cd
5	52.250 ab	39.500	102.500	89.00	8.00 bc
4	55.750 a	39.000	96.250	77.00	9.25 a
3	55.250 a	34.750	95.750	73.50	8.50 b
2	49.500 abc	32.750	107.750	77.00	8.25 b
1	49.750 abc	35.250	96.250	75.50	8.25 b
0	51.000 ab	34.250	94.750	72.75	8.25 b
Pr > F	0.0597	0.5190	0.7063	0.6712	0.0023
LSD (P = 0.1)	6.255	NS	NS	NS	0.739

Note. Values with a common letter are not statistically different. NS = Not significant.

Mean values for plant tissue analysis copper ranged from 7.00 ppm in plots treated with the seven tons per acre rate of broiler litter to 9.25 ppm in the four tons per acre treatment. Mean values for copper were significantly higher in the four tons per acre treatment of broiler litter than in any other treatment. The plots treated with the six and seven tons per acre rates of litter had significantly lower mean values for copper than the zero through four tons per acre rates of broiler litter. The copper value for the plots treated with the five tons per acre rate of litter was significantly higher than those treated with the seven tons per acre treatment of broiler litter. No significant differences in mean plant tissue analysis values for copper were observed among the zero, one, two, three, and five tons per acre broiler litter treatments; the five and six tons per acre rates; or the six and seven tons per acre rates.

The mean values for macro nutrients from plant tissue analysis for the 2014 growing season are displayed in Table 7. The values represent the plant nutrient values for the corn plants at tasseling, following spring applications of broiler litter. The mean values for plant tissue analysis nitrogen ranged from 1.933% in plots treated with the two tons per acre rate of broiler litter to 2.535% in the plots receiving the three tons per acre rate. There was no significant difference in mean nitrogen values among any of the treatments.

Table 7

2014 Mean R1 Corn Plant Tissue Analysis Values for Macro Nutrients

Treatment (Tons/Acre)	N %	P %	K %	Mg %	Ca %	S %
7	2.143	0.335 a	2.488 a	0.208	0.548	0.190
6	2.250	0.335 a	2.500 a	0.205	0.533	0.195
5	2.278	0.285 a	2.148 b	0.195	0.563	0.200
4	2.255	0.325 a	2.488 a	0.218	0.603	0.208
3	2.535	0.288 a	2.010 b	0.230	0.658	0.198
2**	1.933	0.325 a	2.235 ab	0.210	0.578	0.180
1**	2.060	0.303 a	2.093 b	0.213	0.590	0.168
0	2.028	0.225 b	1.555 c	0.270	0.645	0.155
Pr > F	0.7226	0.0086	<0.0001	0.1484	0.8548	0.5772
LSD (P = 0.05)	NS	0.056	0.319	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.
** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

Mean phosphorus values from plant tissue analysis ranged from 0.225% in plots that received the no litter treatment to 0.335% in plots treated with the six and seven tons per acre rates of broiler litter. No statistical differences in mean phosphorus values were observed among plots receiving the one through seven tons per acre rates of broiler litter, however all of the litter treatments tested higher in phosphorus than the no litter treatment.

Mean plant tissue analysis values for potassium ranged from 1.555% in the no litter treatment to 2.5% in the six tons of broiler litter per acre treatment. Plots receiving the four, six, and seven tons per acre rates of litter had significantly higher mean values for potassium than did the plots receiving the zero, one, three, and five tons per acre rates.

Plots receiving the no litter treatment had significantly lower mean values for potassium than plots receiving any rate of litter. No statistical differences in mean potassium values were observed among plots treated with the two, four, six, and seven tons per acre rates of broiler litter or among the one, two, three, and five tons per acre rates.

No significant differences in mean values for plant tissue analysis for magnesium, calcium, or sulfur were observed among any of the treatments. Mean values for plant tissue analysis magnesium ranged from 0.195% in samples collected from plots treated with the five tons per acre rate of broiler litter to 0.27% in plots treated with no broiler litter. Mean values for calcium ranged from 0.533 % in the six ton per acre rate of broiler litter to 0.658% in plots treated with the three ton per acre rate. Mean sulfur values ranged from 0.155% in the no litter treatment to 0.208% in the four ton per acre treatment.

The mean values of micro nutrients from plant tissue analysis from the 2014 corn growing season are displayed in Table 8. No significant differences in mean values for boron, zinc, manganese, iron, or copper from plant tissue analysis were observed among any of the treatments of broiler litter rates. Mean values for boron observed from plant tissue analysis ranged from 4.75 ppm in the two and six tons per acre litter treatments to 7.25 ppm in the seven tons per acre litter treatment. Mean zinc values ranged from 15.25 ppm in the no litter treatment to 19.5 ppm in the four tons of broiler litter per acre treatment. The mean values for manganese were lowest in the one ton per acre treatment at 46.75 ppm and highest in the seven tons per acre treatment at 59.25 ppm. The lowest mean value for iron came from the two tons per acre treatment of broiler litter at 81.00 ppm and the highest was 101.25 ppm from the three tons rate. The lowest mean value for copper was 6.50 ppm from the two tons of broiler litter per acre treatment and the highest was 8.75 ppm from the three tons per acre treatment.

Table 8

2014 Mean R1 Corn Plant Tissue Analysis Values for Micro Nutrients

Treatment (Tons/Acre)	B ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm
7	7.25	18.75	59.25	88.75	7.50
6	4.75	19.00	53.25	84.25	7.00
5	5.75	18.25	47.50	92.25	7.75
4	5.75	19.50	49.00	95.00	8.50
3	5.50	18.00	54.00	101.25	8.75
2	4.75	16.00	47.75	81.00	6.50
1	5.25	15.50	46.75	83.00	7.00
0	5.00	15.25	56.00	85.50	6.75
Pr > F	0.3551	0.4592	0.3628	0.8977	0.7444
LSD (P = 0.05)	NS	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

The soybean yield data for the 2012 broiler litter study is shown in Table 9. In 2012 yields ranged from 47.25 bushels per acre (bu/A) in the plots treated with three tons of broiler litter per acre to 52.06 bu/A in plots treated with the seven tons per acre rates, but no significant differences in yield were observed among treatments.

The 2013 soybean yield data from the broiler litter study is displayed in Table 10. Yields ranged from 64.16 bu/A in the three tons of broiler litter per acre treatment to 83.02 bu/A in the seven ton per acre treatment in 2013. Yields were significantly higher in the seven tons per acre rate treatment than in all other treatments except the one ton per acre rate of broiler litter treatment which was not statistically different. The plots treated with the one ton per acre rate of broiler litter had significantly higher yields than did the zero, three, and five tons per acre rates. Yields were significantly higher in the two and four tons per acre treatments than in the three tons per acre treatment of broiler litter. No significant yield differences were observed among the plots treated with the one, two, four, and six tons per acre rates of broiler litter; the zero, two, four, five, and six tons per acre rates; or the zero, three, five, and six tons per acre rates.

Table 9
Mean Soybean Yields for Broiler Litter Study from 2012

Treatment (Tons of Litter per Acre)	2012 Average Yield (bu/ac.)
7	52.06
6	50.87
5	47.29
4	47.90
3	47.25
2**	47.31
1**	50.99
0	47.50
Pr > F	0.9299
LSD (P = 0.05)	NS

Note. Values with a common letter are not statistically different. NS = Not significant.
** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

Table 10
Mean Soybean Yields for Broiler Litter Study from 2013

Treatment (Tons of Litter per Acre)	2013Average Yield (bu/ac.)
7	83.02 a
6	70.23 bcd
5	67.01 cd
4	72.66 bc
3	64.16 d
2**	70.78 bc
1**	75.65 ab
0	65.57 cd
Pr > F	0.0112
LSD (P = 0.1)	7.892

Note. Values with a common letter are not statistically different. NS = Not significant.
** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

The corn yields for the 2014 growing season are displayed in Table 11. Yields ranged from 82.78 bu/A in the two tons per acre treatment of broiler litter to 131.05 bu./A in the seven tons per acre treatment. Plots receiving the seven tons per acre rate of broiler litter had significantly higher yields than the plots receiving the zero through five tons per acre rates. Statistically higher yields were observed in the plots treated with the six tons per acre rate of broiler litter than in the zero, one, two, and four tons per acre treatments. The plots treated with the three and five tons per acre rates of litter had significantly higher yields than the plots receiving the one and two ton per acre rates.

Table 11

2014 Mean Corn Yields for Broiler Litter Study

Treatment (Tons of Litter per Acre)	Average Yield (bu/ac.)	Average Number of Ears Harvested per Plot Row	Average Ear Weights (Pounds) per Plot Row
7	131.05 a	29.00	0.319 a
6	114.35 ab	26.75	0.298 ab
5	107.44 bc	28.50	0.264 bc
4	92.81 cd	25.75	0.253 bcd
3	106.20 bc	28.00	0.266 bc
2**	82.78 d	27.50	0.209 d
1**	86.20 d	28.75	0.209 d
0	93.16 cd	28.00	0.236 cd
Pr > F	0.0005	0.7690	0.0005
LSD (P = 0.05)	19.015	NS	0.0459

Note. Values with a common letter are not statistically different. NS = Not significant.
** Treatments had previously also received supplemental phosphorus and potassium inorganic fertilizer treatments.

No statistical differences in the average number of ears harvested per plot row were observed among the broiler litter plots. Statistical differences among litter treatments for the average weight of ears harvested per plot were observed. Ear weights ranged from 0.209 pounds in the one and two tons per acre treatments to 0.319 pounds in the seven tons per acre broiler litter treatment. The average ear weight from plots receiving the seven tons per acre rate of litter was statistically higher than all other treatments except the six tons rate, which was not statistically different. Plots treated with the three, five, and six tons per acre rates of broiler litter had statistically higher average ear weights than the plots receiving the one and two tons treatments. No statistical differences in average ear weights were observed among the three through six tons per acre broiler litter treatments or the zero, one, two, and four tons treatments.

There were some significant differences in soil test nutrient levels, as well as, yield. The null hypothesis for objective one was rejected.

Results for Objective 2

The second objective was to determine the effect that treatments of zero, ten, and twenty pounds of elemental copper per acre applied in 2009 had on current soil test copper, plant tissue analysis copper, and yield. The mean soil test values for pH, phosphorus, and potassium from the 2013 growing season are displayed in Table 12. No statistical differences in mean values for soil test pH, phosphorus, and potassium were observed.

The mean soil test values for secondary and micro nutrients from the 2013 growing season are presented in Table 13. No statistical differences in mean values for soil test calcium, magnesium, zinc, boron, manganese, or iron were observed among the copper treatments. Mean soil test values for copper ranged from 2.95 pounds per acre in plots that received no copper to 16 pounds per acre from plots that received the 2009 treatment of twenty pounds per acre of copper. Plots treated with the twenty pounds per acre rate of copper had significantly higher mean values for soil test copper than did the plots treated with no copper or the ten pounds per acre rate. The mean value for copper was significantly higher in plots treated with the ten pounds per acre rate than in the plots that received no copper.

The mean soil test values for primary nutrients plus pH and organic matter from the 2014 growing season are displayed in Table 14. No significant differences in mean values for soil test pH, organic matter, total nitrogen, phosphorus, or potassium were observed among the treatments.

Table 12

2013 Mean Soil Test Values for pH, Phosphorus, and Potassium

2009 Copper Application (lbs/A)	pH	P (lbs/ac)	K (lbs/ac)
0	6.30	47.75	177.75
10	6.44	49.00	174.75
20	6.17	54.00	173.50
Pr > F	0.5128	0.6424	0.9788
LSD (P = 0.1)	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Table 13

2013 Mean Soil Test Values for Secondary and Micro Nutrients

2009 Copper Application	Ca (lbs/ac	Mg (lbs/ac)	Zn (lbs/ac	B (lbs/ac	Cu (lbs/ac)	Mn (lbs/ac)	Fe (lbs/ac)
0	3421.8	212.25	5.38	0.52	2.95 c	424.00	331.50
10	3441.8	192.50	5.75	0.46	9.45 b	474.00	323.00
20	2896.8	193.25	5.50	0.45	16.00 a	431.50	351.50
Pr > F	0.4163	0.2284	0.7225	0.3326	<0.0001	0.4593	0.3225
LSD (P =0.1)	NS	NS	NS	NS	1.4388	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Mean soil test values for secondary and micro nutrients from the 2014 growing season are presented in Table 15. No statistical differences in mean values for soil test calcium, magnesium, zinc, manganese, or iron were observed among the treatments. Mean values for soil test copper ranged from 2.79 lbs/A in the plots that received the no copper treatment to 13.97 lbs/A in the plots treated with the 20 lbs/A rate of liquid copper. Plots treated with the 20 lbs/A rate of liquid copper had statistically higher mean values for soil test copper than the plots treated with the zero or 10 lbs/A rates of copper.

Mean soil test values for copper were also statistically higher in plots treated with the 10 lbs/A rate of copper than those that received no copper.

Tissue samples were collected from this study at R5 for the soybean crop during the 2013 growing season and at R1 for the corn during the 2014 growing season to determine the effect the copper treatments had on plant uptake of copper. Table 16 displays the mean values for plant tissue analysis nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur from the 2013 growing season. No statistical differences in mean plant tissue analysis values for nitrogen, phosphorus, potassium, magnesium, calcium, or sulfur were observed among the treatments.

Table 14

2014 Mean Soil Test Values for Primary Nutrients Plus pH and Organic Matter

2009 Copper Application (lbs/A)	pH	OM (%)	Total N (lbs/ac)	P (lbs/ac)	K (lbs/ac)
0	6.54	2.15	0.14	38.00	170.75
10	6.46	2.15	0.14	45.25	180.00
20	6.25	2.19	0.14	43.75	177.00
Pr > F	0.5929	0.9674	0.9963	0.6915	0.5519
LSD (P = 0.05)	NS	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Table 15

2014 Mean Soil Test Values for Secondary and Micronutrients

2009 Copper Application	Ca (lbs/ac)	Mg (lbs/ac)	Zn (lbs/ac)	Cu (lbs/ac)	Mn (lbs/ac)	Fe (lbs/ac)
0	3560.50	199.25	5.03	2.79 c	382.50	145.00
10	3206.00	179.00	5.10	7.61 b	393.50	147.50
20	2866.00	185.00	5.10	13.97 a	378.50	156.50
Pr > F	0.5225	0.3610	0.9879	<0.0001	0.8191	0.3985
LSD (P =0.05)	NS	NS	NS	1.64	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

The mean values for micro nutrients from plant tissue analysis of soybean leaves collected at the R5 growth stage for the 2013 growing season are displayed in Table 17.

The mean values for plant tissue analysis copper ranged from 7.5 ppm in plots treated with the 20 lbs/A rate of copper to 8 ppm in plots where no copper was applied. No statistical difference in mean plant tissue analysis copper was observed among the treatments. There was also no statistical differences observed among treatments for plant tissue analysis boron, zinc, manganese, or iron.

The mean values for macro nutrients of corn ear leaves collected at the R1 growth stage during the 2014 growing season are presented in Table 18. No statistical difference in mean values for nitrogen, phosphorus, potassium, magnesium, calcium, or sulfur from plant tissue analysis were observed among the treatments.

Table 16
2013 Mean R5 Soybean Plant Tissue Analysis Values for Macro Nutrients

2009 Copper Application (lbs/A)	N %	P %	K %	Mg %	Ca %	S %
0	5.31	0.28	1.18	0.35	1.47	0.27
10	5.53	0.29	1.34	0.30	1.42	0.28
20	4.34	0.29	1.23	0.31	1.49	0.27
Pr > F	0.1402	0.6232	0.3081	0.5027	0.8106	0.4219
LSD (P = 0.1)	NS	NS	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

The mean values for micro nutrients from plant tissue analysis from the 2014 growing season are displayed in Table 19. The mean values for plant tissue analysis copper ranged from 10.75 ppm in plots treated with the 10 lbs/A rate of copper up to 12.5 ppm in plots treated with the 20 lbs/A rate. There was no statistical difference in plant tissue analysis copper among any of the treatments. No statistical differences were observed among the copper treatments for plant tissue analysis boron, zinc, manganese, or iron.

Three years of yield data were collected from 2012 to 2014 to determine if the 2009 copper applications influenced yield. The study was planted in soybeans during the

2012 and 2013 growing seasons and corn during the 2014 growing season. The mean yield data for the 2012 growing season is presented in Table 20. Average yields ranged from 51.24 bu/A in the plots treated with no copper up to 53.93 bu/A in the plots that received the 10 lbs/A treatment of copper. No statistical difference in yield was observed among the copper treatments.

Table 17

2013 Mean R5 Soybean Plant Tissue Analysis Values for Micro Nutrients

2009 Copper Application (lbs/A)	B ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm
0	43.5	33.25	118.75	73.75	8.00
10	41.8	33.50	110.00	77.25	7.75
20	41.3	36.75	118.75	89.25	7.50
Pr > F	0.7268	0.2619	0.6655	0.4788	0.7443
LSD (P = 0.1)	NS	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Table 18

2014 Mean R1 Corn Plant Tissue Analysis Values for Macro Nutrients

2009 Copper Application (lbs/A)	N %	P %	K %	Mg %	Ca %	S %
0	3.08	0.30	1.33	0.32	1.03	0.23
10	3.13	0.27	1.46	0.26	0.87	0.20
20	3.33	0.29	1.53	0.26	0.88	0.21
Pr > F	0.7021	0.5761	0.7274	0.2656	0.1409	0.1694
LSD (P = 0.05)	NS	NS	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Table 19

2014 Mean R1 Corn Plant Tissue Analysis Values for Micro Nutrients

2009 Copper Application (lbs/A)	B ppm	Zn ppm	Mn ppm	Fe ppm	Cu ppm
0	6.75	28.00	63.00	122.75	11.75
10	6.50	23.75	55.75	105.00	10.75
20	6.50	27.25	66.50	115.50	12.50
Pr > F	0.9589	0.3820	0.2246	0.3970	0.5261
LSD (P = 0.05)	NS	NS	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

The mean yield data for the soybeans grown in 2013 is displayed in Table 21. Average yields ranged from 69.38 bu/A in the plots treated with the 20 lbs/A rate of copper up to 72.19 bu/A in the plots receiving the 10 lbs/A copper treatment. There was no statistical difference in yield among the treatments.

Table 20
Mean Soybean Yields for Copper Study from 2012

2009 Copper Application (lbs/A)	Average Yield (bu/ac.)
0	51.24
10	53.93
20	53.47
Pr > F	0.7724
LSD (P = 0.05)	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

The mean yield data, average number of ears per plot harvested, and average ear weights for the corn grown in 2014 is presented in Table 22. The average yields ranged from 126.19 bu/A in the plots receiving no copper to 143.12 bu/A in the plots treated with the 10 lbs/A rate of copper. The average number of ears harvested per plot ranged from 26.75 in the plots that received no treatment of copper to 28.75 in the plots treated with the 10 and 20 lbs/A rates of copper. The average weight of the harvested ears ranged from 0.325 pounds in the plots treated with the 20 lbs/A rate of copper to 0.348 pounds in the plots receiving the 10 lbs/A treatment of copper. No statistical differences in yield, number of ears harvested, or ear weights were observed among the copper treatments.

Table 21
Mean Soybean Yields for Copper Study from 2013

2009 Copper Application (lbs/A)	Average Yield (bu/ac.)
0	70.12
10	72.79
20	69.38
Pr > F	0.7846
LSD (P = 0.1)	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Table 22
Mean Corn Yields for Copper Study from 2014

2009 Copper Application (lbs/A)	Average Yield (bu/ac.)	Average Number of Ears Harvested per Plot Row	Average Ear Weights (Pounds) per Plot Row
0	126.19	26.75	0.336
10	143.12	28.75	0.348
20	134.28	28.75	0.325
Pr > F	0.3043	0.5559	0.1130
LSD (P = 0.05)	NS	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Conclusion

Chapter four presented the data collected from the 2013 and 2014 growing season, along with the yield data from the 2012 broiler litter and copper studies. There were significant differences in soil test and plant tissue analysis nutrient values among the treatments in the broiler study. 2012 saw no significant differences in yield among the broiler litter treatments, in contrast to 2013 and 2014 where yield differences were observed among treatments. A statistical difference in soil test copper was observed among the copper treatments in 2014, however no statistical differences in copper from plant tissue analysis were observed among treatments. No statistical differences in yield were observed among the copper treatments.

Chapter 5

Conclusions and Recommendations

Introduction

Chapter four presented yield data from 2012 through 2014 growing seasons for both the long-term broiler litter and copper studies, as well as the soil test and plant tissue analysis data for both studies from the 2013 and 2014 growing seasons. Chapter five will discuss conclusions from the broiler litter and copper studies based on the results presented in chapter four. In this chapter recommendations will also be made for future related research, as well as recommendations for using broiler litter and copper applications as part of a fertility plan.

Conclusions for Objective 1

Soil Test results from the broiler litter study in 2013 and 2014 revealed that mean soil pH values were statistically higher in 2013 plots treated with the six and seven tons per acre rates of litter than in plots receiving the one and two tons rates of litter; however, in 2014 mean pH values for the six and seven tons rates were not statistically different from the no litter treatment. This differs from the observation of Scott (2010) of no statistical difference among treatments. The findings are somewhat in line with the observations of Netthisinghe et al. (2016), where over a ten year period, corn fertility from only annual rates of 7.6 to 9.0 tons per acre of broiler litter raised soil pH by an average 0.3 units over the first eight years, but pH dropped by 0.4 units of the initial level between the 8th and 11th years. Netthisinghe et al. (2016) attributed the drop in pH levels over the final three years of the study to reduced amounts of calcium supplied in the litter over that span.   With the exception of the three tons per acre treatment of broiler litter in 2013, mean values for soil organic matter from 2013 and 2104 were statistically lower in the no litter treatment than in any of the plots treated with broiler litter. In 2013 the five and six tons treatments were statistically higher in organic matter than the zero, two, and three tons treatments, while in 2014 mean values for organic matter were statistically higher in the five through seven tons treatments than in the two through four tons per acre treatments of broiler litter. The findings of Scott (2010) were similar in that the no litter treatment was statistically lower in organic matter than any litter treatment, but no statistical differences were observed among the plots receiving litter. The observations of Netthisinghe et al. (2016), also agree that long term use of broiler builds soil organic matter, as plots receiving annual applications of 7.6 to 9.0 tons per acre rates of broiler had statistically higher mean soil organic matter levels than plots receiving only inorganic fertilizers during that time period. According to Rasnake (1996), broiler litter can raise soil pH and increase organic matter.

Mean soil test total nitrogen values seemed to be higher in plots treated with the higher rates of broiler litter. In both 2013 and 2014 plots treated with the five through seven tons per acre rates of litter had statistically higher values for total nitrogen than did the plots receiving the lower rates of zero and three tons per acre. Broiler litter applications contributing to increased total nitrogen content in soils is supported by Netthisinghe et al. (2016), as plots receiving annual applications of broiler litter over a ten year period saw mean total nitrogen values increase from 0.12% at the beginning of the study to 0.29% by the end. Over the same time period mean total nitrogen from plots receiving only inorganic fertilizers increased by only 0.03% (Netthisinghe et al., 2016).

In both 2013 and 2014 mean soil test phosphorus values were statistically highest in the plots treated with the seven tons rate of litter and lowest in the no litter treatment. The two, five, and six tons per acre treatments also ranked among the highest in mean phosphorus values for both years. These observations were similar to those of Scott (2010) where the seven, six, two, and one tons per acre rates of broiler litter were statistically higher in phosphorus than the zero, three, and four tons per acre rates. The higher mean phosphorus values from the one and two tons rates of litter were likely due to the 2005, 2006, and 2009 applications of commercial phosphorus and potassium fertilizers. Observations by Netthisinghe et al. (2016) support the findings that continuous applications of broiler litter raise soil test phosphorus levels. After ten years of supplying corn fertility from broiler litter alone, soil test phosphorus levels increased from 163.8 lbs/A at the beginning of the study to 956.8 lbs/A by the conclusion of the study (Netthisinghe et al., 2016). To further illustrate how continual broiler litter use builds phosphorus levels in the soil, the mean soil test phosphorus values for every treatment were in the very high range, based on the University of Kentucky's AGR-1 publication, except the three tons per acre broiler litter treatment in 2013 and the no litter treatment for both the 2013 and 2014 samples (Murdock and Ritchey, 2012).

In general soil test values for potassium were highest in the plots receiving the highest historical rates of broiler litter or commercial fertilizers. Mean values for soil test potassium were statistically higher in plots treated with the seven tons per acre rate of broiler litter than all other treatments except the two and six tons per acre treatments in

2013. The seven tons per acre rate of broiler litter was statistically higher in soil test potassium in 2014 than any of the other treatments. Observations by Scott (2010) showed that the treatments of one, two, and seven tons per acre rates of broiler litter had the highest soil test potassium values. Again the reason the one and two tons per acre treatments had high values for potassium is because of the 2005, 2006, and 2009 applications of commercial potassium fertilizers to those treatments.

Mean soil test values for magnesium were generally higher in the plots treated with the higher rates of broiler litter. In 2013 the plots treated with the four through seven tons rates of broiler litter were statistically higher in magnesium than the three tons rate and the no litter treatment. The 2014 soil test results were much the same as the five through seven tons rates of litter had higher magnesium values than the zero, one, and two tons rates. Scott (2010) observed similar results to the 2013 findings, except that the no litter treatment was statistically lower in magnesium than any of the treatments that received litter.

For the most part there was little difference in soil test calcium among the treatments. In 2013 there was no statistical difference in soil test calcium among the one through seven tons treatments, but all treatments that received any rate of litter were statistically higher than the no litter treatment. Soil test results in 2014 were very similar with no significant differences in calcium values observed among any of the broiler litter treatment. The 2013 and 2014 soil test results for calcium were similar to the observations of Scott (2010) who also saw no statistical difference in calcium values among any of the treatments.

Results from 2013 and 2014 soil samples were similar in regards to soil test zinc values. In both years the zinc values were highest in the seven tons rate of litter, followed by the five and six tons rates. The zinc values were lowest in the no litter treatment, but there was no statistical difference between the zero and one ton rate. The 2013 and 2014 soil test results were in line with the observations of Scott (2010) with zinc values being the highest in the plots treated with the higher rates of broiler litter and lowest in the plots receiving the lower rates. The work of Netthisinghe et al. (2016) supports these findings as corn plots treated with only annual rates of 7.6 to 9.0 tons per acre of broiler litter and to a lesser extent plots that received half of their corn fertility from broiler litter and half from inorganic fertilizers, significantly increased soil test zinc levels over a ten year period. Plots treated with only inorganic fertilizers did not significantly change soil test zinc levels over the same time period (Netthisinghe et al., 2016).

The mean soil test values for copper in 2013 and 2014 followed a similar pattern to zinc, as the highest copper values were observed in the higher treatments of broiler litter and declined steadily as the rate of litter applied lowered. The soil test results by Scott (2010) for copper followed a similar pattern. The observations of soil test copper being increased by broiler litter applications is supported by the findings of Netthisinghe et al. (2016), who observed that annual applications of 7.6 to 9.0 tons/A of broiler litter increased soil test copper from 7.4 lbs/A to 31.4 lbs/A over the ten years the study was conducted, but observed that soil test copper was not significantly changed by applications of inorganic fertilizers alone.

Soil test manganese values did not seem to be effected by the amount of broiler litter applied as the highest values for both years came from the no litter treatment, however those values were not significantly different from other treatments of moderate to high rates of broiler litter.

In 2013 the no litter treatment was significantly lower in soil test iron than any rate of broiler, with the exception of the three tons per acre rate, which was not significantly different. No significant difference in soil test iron was observed among the broiler treatments in 2014. These findings differ from those of Netthisinghe et al. (2016), who observed that annual applications of 7.6 to 9.0 tons of broiler litter per acre over a 10 year period increased soil test iron levels from 263.4 lbs/A at the beginning of the study to 350.8 lbs/A by the study's conclusion.

The 2013 R5 soybean and 2014 R1 corn leaf tissue analysis revealed no statistical difference in plant uptake of nitrogen among any of the treatments. Scott (2010) also observed no statistical difference in nitrogen uptake from 2009 R2 leaf tissue analysis and R6 whole plant tissue analysis. Plant uptake of phosphorus was significantly lower in plots treated with no litter compared to plots receiving any rate of litter in 2013 and 2014. In the soybeans in 2013 there was no statistical difference in plant uptake of phosphorus among the plots treated with the one through six tons per acre rates of litter, however the plots treated with the three tons per acre rate of phosphorus had statistically higher levels of phosphorus than those treated with the seven tons rate. There was no statistical difference in plant uptake of phosphorus among the one through seven tons per acre rates of broiler litter in the corn in 2014. Scott (2010) observed statistical differences in both the R2 and R6 tissue samples as the plots treated with the seven, six, two, and one tons rate of broiler litter had the highest values for phosphorus uptake.

No significant difference in plant uptake of potassium was observed from the R5 soybean leaf tissue analysis in 2013. The R1 leaf tissue analysis from the corn in 2014 showed that plant uptake of potassium in plots treated with no litter was statistically lower than in plots receiving any rate of broiler litter. Plots treated with the seven, six, four and two tons rates had the highest values for plant tissue analysis potassium. Observations from Scott (2010) of the plant tissue analysis results for potassium were similar to the 2014 results, with the seven, six, two, and one tons rates having the highest values for potassium.

Plant tissue analysis from R5 soybean leaf samples in 2013 and R1 corn ear leaf samples in 2014 revealed no significant difference in magnesium uptake among the broiler litter treatments. Although not significant, magnesium values were lowest in the six and seven ton per acre broiler litter treatments in 2013 and five through seven ton treatments in 2014. Scott (2010) made similar observations, as R6 whole plant samples from the plots treated with no litter and the three through five tons per acre rates of broiler litter had the highest levels of magnesium.

No statistical difference in plant uptake of calcium was observed from R5 soybean leaf tissue analysis in 2013 or R1 corn ear leaf analysis in 2014. These findings differed from the observations made by Scott (2010) from R2 soybean tissue samples, where the highest values for calcium came from the no litter treatments and the lowest values came from the higher fertility treatments of broiler litter or commercial fertilizer.

Later in the growing season, from R6 whole plant tissue analysis, differences in calcium uptake did not seem to follow a pattern based on fertility (Scott, 2010)

Similar to the observations for calcium uptake, there was no statistical difference in values for sulfur uptake among treatments in 2013 and 2014. These findings were supported by Scott (2010), who also observed no statistical in plant uptake of sulfur among the broiler litter treatments.

There was not a consistent pattern in boron values from plant tissue analysis samples from the 2013 growing season. In the 2013 R5 soybean leaf samples, the lowest values for boron came from the plots that received the highest rates of broiler litter or commercial fertilizer, with the seven tons of broiler litter per acre treatment having the lowest value of all. No statistical difference in plant uptake of boron was observed from the corn ear leaf samples in 2014. The 2014 observations from the corn were consistent with the findings of Scott (2010), from R2 leaf and R6 whole plant soybean tissue analysis, of no statistical difference in boron uptake among treatments of broiler litter.

No statistical differences in plant uptake of zinc were observed from analysis of either the R5 soybean leaf or R1 corn ear leaf samples. These findings were supported by Scott (2010), who observed no statistical difference in plant uptake of zinc from R6 whole plant tissue samples, however statistical differences were observed from V5 and R2 leaf samples taken earlier in the growing season.

No statistical differences in plant uptake of manganese were observed from the R5 soybean leaf tissue samples in 2013 or the R1 corn leaf samples in 2014. Scott (2010) made similar observations, as R2 soybean leaf samples revealed no statistical difference in manganese concentrations among the one through seven tons treatments of broiler litter, but the no litter treatment was statistically higher in manganese than all other treatments except the two tons rate. By R6, Scott's whole plant tissue samples showed no statistical difference in uptake of manganese (2010).

No statistical difference in iron uptake was observed among the treatments from R5 soybean leaf or R1 corn leaf tissue analysis. Scott (2010) also observed no statistical difference in plant uptake of iron from R6 and R2 tissue analysis.

A statistical difference in copper uptake was observed in the 2013 R5 soybean leaf samples, but it was not what was expected. The lowest values came from the plots treated with the six and seven tons per acre rates of broiler litter, while the samples from the four tons treatment were statistically higher in copper than any other treatment. No statistical differences in plant uptake of copper were observed among the R1 corn leaf tissue analysis in 2014. Scott (2010) observed similar results from soybean tissue analysis to those from both the 2013 soybeans and the 2014 corn. Scott (2010) observed from R2 soybean leaf samples that copper values were statistically highest in plots treated with the no litter and the three through four tons per acre rates of broiler litter than in the plots receiving the higher historical rates of broiler litter or commercial fertilizer. Although Scott (2010) saw statistical differences in copper uptake from R2 leaf samples, no statistical differences were seen from R6 whole plant tissue analysis.

2012 was a fairly dry growing season which probably led to the lower yields and lack of significant differences among the treatments. Just 2.03 inches of rain fell from the time the soybeans were planted on May 24th through July 7th and there were additional extended dry periods in August as well (Kentucky Mesonet, 2012). When less than adequate moisture is available it is difficult for differences in fertility to be seen, because water is the limiting factor. The 2012 mean yields, though lower than soybean yields of Scott (2010), were similar in that no statistical differences were observed among treatments.

The increased and more consistent rainfall received in the 2013 growing season allowed for higher yields and statistical yield differences among treatments. The seven tons per acre broiler litter treatment had the highest mean yield in 2013, as would be expected from the higher fertility, but was not statistically different from the one ton treatment. Treatments of one, two, four, and six tons of broiler litter per acre were statistically similar and were among the highest yielding treatments. The one and two tons treatments probably ranked near the top, because of the 2005, 2006, and 2009 applications of high rates of commercial phosphorus and potash. The treatments of three tons and no litter yielded the lowest most likely because historically they received the lowest rates of fertility, however mean yield for the no litter treatment was not statistically different from the two, three, four, five, and six tons per acre treatments of broiler litter.

Although the 2014 growing season was the driest of the three years, the nitrogen from the spring broiler litter treatments that were applied also influenced yield. The results from the analysis of the broiler litter, found in Appendix E, showed that the litter contained seventy-four pounds of nitrogen per ton. Roughly sixty pounds of that came in the form of organic nitrogen, which according to the University of Kentucky's AGR-1 Publication 2012-13 Nutrient and Lime Recommendations, can range in availability from twenty to eighty percent in the year it is applied (Murdock & Ritchey, 2012). As expected the plots treated with the higher rates of litter yielded highest, as the seven ton treatment yielded the highest, but was not significantly higher than the six ton rate. The next highest yields came from the plots treated with the three and five tons per acre rates of broiler litter. The mean yield of the no litter treatment was surprising in that even with no nitrogen applied, there was no statistical difference in the no litter treatment yield and the yields of the one through five tons of broiler litter treatments.

Conclusions for Objective 2

Statistical differences in mean soil test copper were found among treatments for both the 2013 and 2014 growing seasons in the copper study. In both years the plots receiving the 2009 pre-plant application of twenty pounds per acre of copper had statistically higher mean soil test copper values than the plots receiving the ten pounds per acre rate or those receiving no copper at all. The plots that were treated with the ten pound rate of copper in 2009 also had higher mean soil test copper values than the plots that did not receive a copper treatment. The mean soil test copper values from the 2013 and 2014 growing seasons mirrored what Scott (2010) observed during the first year of the study in 2009.

No statistical differences in mean leaf tissue analysis copper values were observed from the R5 soybean samples in 2013 or the R1 corn samples in 2014. These results are similar to the findings of Scott (2010) from V5 and R2 leaf samples, as well as, R6 whole plant tissue samples, where no statistical difference in plant uptake of copper was observed among the copper treatments. Oplinger and Ohlrogge (1974) observed significant differences in plant uptake of copper between soybeans receiving a 40 lbs/A rate of copper and soybeans that received no copper, but the differences were observed from early season samples and the differences were not seen in samples collected later in the season. Significant differences in copper concentrations from corn tissue samples between treated and untreated plots were also observed by Oplinger and Ohlrogge (1974) as copper concentrations tended to be higher in treated plots throughout the growing season, but by the second and third year of the study differences in copper concentrations were greater in samples pulled prior to tasseling. The copper concentrations from the 2013 R5 soybean leaf tissue analysis ranged from 7.50 ppm to 8.00 ppm and the 2014 R1 corn ear leaf copper concentrations ranged from 10.75 ppm to 12.50 ppm. According to the University of Kentucky extension publication, AGR-192 Sampling Plant Tissue for Nutrient Analysis, copper concentrations in flowering soybeans should range from 4 ppm to 30 ppm and from 5 ppm to 25 ppm in tasseling corn (Schwab et al., 2007). The samples collected from each crop fell within the sufficiency range for copper, but AGR-192 does not give a sufficiency range for R5 soybean samples and the R2 soybean leaf samples were lost in the mail.

Although there were no statistical differences in yield among the copper treatments, there was a strong trend of the ten pound per acre rate of copper being the highest yielding treatment in all three years of the study. In every year but 2013, the twenty pound rate of copper out yielded the control. These findings were in line with Scott's 2009 work, where no statistical differences were observed among treatments, but the ten pound rate was the highest yielding treatment (Scott, 2010). Oplinger and Ohlrogge (1974) observed significant yield increases in corn and soybeans from grower field trials on Maumee sandy loams, but did not observe the same yield increases on muck soils high in organic matter, which binds copper. Berger and Troug (1949) observed significant increases in sweet corn yield from copper applications, however the yield increases came on a Miami silt loam that was relatively low in organic matter and the same results were not seen on the Carrington silt loam, high in organic matter.

Recommendations for Future Research

A few small changes to both studies could help make the data collected more meaningful. The corn in the 2014 broiler litter study was lacking in nitrogen in the plots treated with the lower rates of litter. The lack of nitrogen in some treatments delayed the maturity of the plots treated with the lower rates of broiler litter, so much so that it was difficult to find ten ear leaves for tissue analysis when the plots treated with the higher rates of litter were already tasseling. The insufficient amount of nitrogen also lead to lower yields compared to the plots treated with higher rates of broiler litter. Applying a standard amount of nitrogen to every plot would make it easier to observe if other nutrients from the litter were influencing yield.

In all three years of the copper study, though not statistically different, the plots treated with the ten pound per acre rate of soil applied copper in 2009 were the highest yielding of the three treatments. It might be beneficial to repeat the study and add a five and fifteen pound per acre treatment of soil applied copper to determine if there is an optimum rate between the existing rates that might show a statistical difference in yield.

Oplinger and Ohlrogge (1974) observed significantly larger soybean seed size from plots treated with a 20 lbs/A rate of either copper sulfate or copper oxide compared to plots receiving no application of copper. Measuring soybean seed size with calipers could help determine the effect of copper treatments on seed size.

To better understand how and at what growth stage copper influences crop yield, multiple plant tissue samples at different growth stages are needed. Scott pulled leaf tissue samples at V5 and R2 and whole plant samples at R6 from the soybeans in 2009 (Scott, 2010). Oplinger and Ohlrogge (1974) observed that differences in copper concentrations between plots treated with copper and untreated plots were, at times, greater in samples pulled earlier in the season than those pulled later in the season for both corn and soybeans. When looking at copper uptake of soybeans and corn from applications of eleven, twenty-two, and forty-four tons per acre of sewage sludge, Reddy et al. (1989) collected whole plant samples at R2 from the soybeans and ear leaf samples at silking in the corn. Reddy et al. (1989) also collected grain samples from the soybeans and grain and stem samples from the corn at harvest to determine the concentrations of copper in both crops in different parts of the plants at different growth stages. A combination of sampling different parts of the plant such as leaf, stem, and grain at different growth stages throughout the growing season might be necessary to better understand how copper influences corn and soybean yield.

Recommendations for Future Practitioners

Growers looking to use broiler litter in their fertility plans should probably base their application rates on regular soil tests and the phosphorus and potash needs of their crop. Basing rates on nitrogen can lead to excessive soil test levels of phosphorus. Long term use of high rates of broiler litter can build nutrient levels in the soil as determined by soil testing regularly; growers might be able to utilize the residual fertility from previous year's applications and not have to apply as much or any fertilizer some years.

Although a strong trend of a ten pound per acre rate of soil applied copper increasing corn and soybean yield compared to the control has been observed, more research needs to be conducted before this practice can be recommended to producers.

Conclusions

Chapter five provided interpretation of the results presented in chapter four, as well as suggestions for future research on the topic and advice to growers considering using broiler litter in their fertility program.

In general, the pH, organic matter, and total nitrogen values from soil analysis tended to be higher in the plots historically treated with the higher rates of broiler litter. As a result of 2005, 2006, and 2009 applications of commercial phosphorus and potash fertilizers to the one and two tons per acre broiler litter treatments, the two tons per acre treatment of broiler litter along with the five, six, and seven tons per acre treatments had the highest values for soil test phosphorus and potassium.

No statistical differences in soil test calcium were observed among the one through seven tons per acre broiler litter treatments. Plots receiving the historical rates of four through seven tons per acre of litter tended to have the highest mean values for soil test magnesium. Mean zinc and copper values were highest in plots that received past treatments of the seven tons per acre rate of broiler litter and soil test values for both nutrients declined steadily as the rate of litter applied was reduced. There was no clear pattern for mean soil test manganese values, as the highest values in both years came from the no litter treatment, but the values were not statistically different from other moderate to high rates of broiler litter. Though not statistically different from all other treatments soil test values for iron in both years were lowest in the no litter and three tons per acre treatments of broiler litter.

2013 R5 soybean leaf and 2014 R1 corn ear leaf analysis revealed no statistical differences in nitrogen uptake among treatments. Though there were only a few statistical differences in phosphorus concentrations in plant tissue samples among broiler litter treatments, in both years the no litter treatment had a statistically lower mean phosphorus concentration than any treatment that received a historical rate of litter. Potassium concentrations were statistically higher in the seven tons per acre treatment of broiler litter than the no litter treatment in both years, though not significantly different in the 2013 soybean leaf tissue samples. In both 2013 and 2014 no significant differences in plant uptake of magnesium, calcium, or sulfur were observed among the broiler litter treatments. No statistical differences in plant concentrations of zinc, manganese, and iron were observed among treatments in either year. Soybean leaf tissue analysis concentrations of boron were lowest in plots treated with the seven tons per acre rate of broiler litter and no statistical difference was observed among treatments from the R1 corn ear leaf tissue analysis. Copper concentrations did not follow a consistent pattern between years, as concentrations were lowest in the plots treated with past rates of six and seven tons of broiler litter per acre in the 2013 soybeans, but in the corn in the following year no statistical differences in copper concentrations were observed among the treatments.

Yields for the broiler litter study varied among years. Several extended dry periods contributed to lower soybean yields and no statistical differences being seen during the 2012 growing season. More consistent rainfall in 2013 allowed for statistical differences in yield to be seen among treatments. Plots receiving historical treatments of seven tons of broiler litter per acre yielded statistically higher than every other treatment except the one ton treatment. In 2014, nitrogen from spring applications of broiler litter to the corn impacted yield. In general yields were higher in plots treated with the higher rates of litter.

Soil test results from the copper study showed that soil test copper values were statistically higher in plots receiving the 2009 treatment of 20 lbs/A rate of soil applied copper, than the plots treated with the 10 lbs/A rate or no copper at all. In both years that soil samples were taken, the plots that were treated with the 10 lbs/A rate of copper in 2009, had statistically higher soil test values for copper than the plots that received no copper. Despite the statistical differences in soil test copper among treatments, no statistical differences in copper concentrations were observed from plant tissue analysis of R5 soybean leaf analysis or R1 corn ear leaf analysis. Although no statistical differences in yield were observed among the copper treatments in any of the three years, a strong trend of the plots receiving the 2009 treatment of 10 lbs/A rate of soil applied copper yielding the highest among treatments all three years was observed.

Applying a set rate of nitrogen to every treatment in the broiler study in years that the plots are planted to corn might make it easier to see the impact other nutrients, provided by the litter, have on yield. Because the 10 lbs/A treatment of copper applied in 2009, has consistently yielded highest among treatments, repeating the copper study, but adding a five and fifteen pound per acre rate of copper might help to determine an optimum rate to apply that might show a statistical difference in yield. Measuring soybean seed to determine if the copper applications have an effect on seed size, might provide a better understanding of how copper influences soybean yield. Collecting leaf, stem, and grain tissue samples at different crop growth stages might provide a better understanding of how copper influences yield.

Because broiler litter contains large amounts of phosphorus, producers applying litter as part of their fertility plan should base their rates and applications on soil testing and the phosphorus needs of the crop. Long term use of broiler litter could build soil test phosphorus values high enough so that the field may not need any phosphorus for a few years. More research needs to be conducted with copper applications before it can be recommended as a practice to producers.

Appendix A

Plot Plans

Broiler Litter Study Plot Layout

Plot 8 Treatment 0	Plot 16 Treatment 0	Plot 24 Treatment 7	Plot 32 Treatment 7
Plot 7 Treatment 6	Plot 15 Treatment 3	Plot 23 Treatment 5	Plot 31 Treatment 4
Plot 6 Treatment 5	Plot 14 Treatment 6	Plot 22 Treatment 4	Plot 30 Treatment 1
Plot 5 Treatment 1	Plot 13 Treatment 1	Plot 21 Treatment 0	Plot 29 Treatment 3
Plot 4 Treatment 4	Plot 12 Treatment 5	Plot 20 Treatment 2	Plot 28 Treatment 2
Plot 3 Treatment 3	Plot 11 Treatment 2	Plot 19 Treatment 6	Plot 27 Treatment 0
Plot 2 Treatment 2	Plot 10 Treatment 4	Plot 18 Treatment 1	Plot 26 Treatment 6
Plot 1 Treatment 7	Plot 9 Treatment 7	Plot 17 Treatment 3	Plot 25 Treatment 5

← North

Copper Study Plot Layout

Cu 10 Treatment 2	Cu 11 Treatment 3	Cu 12 Treatment 1
Cu 7 Treatment 3	Cu 8 Treatment 2	Cu 9 Treatment 1
Cu 4 Treatment 1	Cu 5 Treatment 3	Cu 6 Treatment 2
Cu 1 Treatment 1	Cu 2 Treatment 2	Cu 3 Treatment 3

← North

Appendix B

Stand Counts

Table 1

2013 Soybean Stand Counts from Broiler Litter Study

Treatment (Tons of Litter per Acre)	Average Number of Plants per 5 ft. of row	Average Number of Plants per Acre
7	17.50	122377.6
6	17.75	124125.9
5	16.81	117569.9
4	18.13	126748.3
3	18.25	127622.4
2	17.56	122814.7
1	17.44	121940.6
0	18.69	130681.8

Table 2

2014 Corn Stand Counts from Broiler Litter Study

Treatment (Tons of Litter per Acre)	Average Number of Plants per 10 ft. of row	Average Number of Plants per Acre
7	19.06	33214.5
6	19.13	33323.4
5	18.38	32016.6
4	17.81	31036.5
3	19.25	33541.2
2	18.06	31472.1
1	18.69	32561.1
0	18.81	32778.9

Table 3

2014 Corn Stand Counts from Copper Study

2009 Copper Application (lbs./A)	Average Number of Plants per 10 ft. of row	Average Number of Plants per Acre
0	17.13	29838.6
10	17.56	30600.9
20	18.00	31363.2

Appendix C

Height and Lodging Data

Table 1

2013 Mean Soybean Plant Heights and Lodging Ratings From Broiler Litter Study

Treatment (Tons of Litter per Acre)	Plant Height (Inches)	Lodging Ratings (%)
7	49.63	52.50
6	51.50	57.50
5	50.25	57.50
4	50.06	45.00
3	47.88	47.50
2	49.88	55.00
1	49.50	52.50
0	49.19	47.50
Pr > F	0.1814	0.4984
LSD (P = 0.1)	NS	NS

Note. Values with a common letter are not statistically different.

Table 2

2014 Mean Corn Plant Heights from Broiler Litter Study

Treatment (Tons of Litter per Acre)	Plant Height (Inches)
7	77.30 a
6	68.20 b
5	66.20 bc
4	60.45 de
3	61.95 cde
2	63.95 bcd
1	58.25 e
0	57.35 e
Pr > F	<0.0001
LSD (P = 0.1)	5.0619

Note. Values with a common letter are not statistically different.

Table 3

2013 Mean Soybean Plant Heights and Lodging Ratings From Copper Study

2009 Copper Application (lbs./A)	Plant Height (Inches)	Lodging Ratings (%)
0	48.69	35.00
10	48.63	37.50
20	48.56	32.50
Pr > F	0.9890	0.6141
LSD (P = 0.05)	NS	NS

Note. Values with a common letter are not statistically different. NS = Not significant.

Table 4

2014 Mean Corn Plant Heights from Copper Study

2009 Copper Application (lbs./A)	Plant Height (Inches)
0	63.55
10	68.90
20	67.35
Pr > F	0.1589
LSD (P = 0.05)	NS

Note. Values with a common letter are not statistically different.

Appendix D

Leaf Temperature Readings

Table 1

2014 Corn Mean Leaf Temperature Readings from Broiler Litter Study

Treatment (Tons of Litter per Acre)	Leaf Temperature (Ear Leaf) (F^o) 7/26/2014	Leaf Temperature (2 Leaves Above Ear Leaf) (F^o) 8/23/2014
7	84.75	87.96
6	82.24	86.34
5	82.79	85.98
4	84.57	88.17
3	83.62	87.97
2	85.26	88.68
1	84.77	88.17
0	83.08	87.26
Pr > F	0.3623	0.1375
LSD (P = 0.05)	NS	NS

Note. Values with a common letter are not statistically different.

Appendix E

2014 Broiler Litter Analysis

Table 1

2014 Broiler Litter Analysis from Waters Agricultural Laboratories

	Sample #1		Sample #2		Average	
Nutrient	%	Lbs/Ton	%	Lbs/Ton	%	Lbs/Ton
Nitrogen - Total	3.700	74.00	3.120	62.40	3.410	68.20
Ammonia Nitrogen	0.590	11.80				
Nitrate Nitrogen	0.103	2.06				
Organic Nitrogen	3.007	60.14				
P_2O_5 - Total	2.950	59.00	3.080	61.60	3.015	60.30
K_2O - Total	3.610	72.20	3.920	78.40	3.765	75.30
Calcium	2.010	40.20	1.970	39.40	1.990	39.80
Magnesium	0.610	12.20	0.680	13.60	0.645	12.90
Sulfur	0.870	17.40	1.010	20.20	0.940	18.80
Boron	0.005	0.10	0.005	0.10	0.005	0.10
Zinc	0.040	0.80	0.040	0.80	0.040	0.80
Manganese	0.055	1.10	0.057	1.14	0.056	1.12
Iron	0.020	0.40	0.015	0.30	0.018	0.35
Copper	0.052	1.04	0.055	1.10	0.054	1.07
Aluminum	0.024	0.48	0.012	0.24	0.018	0.36
Sodium	0.950	19.00	1.010	20.20	0.980	19.60
Moisture	16.66		19.07		17.865	
C:N Ratio	8.40:1					

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