DETERMINATION OF NITROGEN AVAILABILITY FROM ANIMAL MANURE AMENDED SOILS

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INTRODUCTION

Manure has historically been applied to crop and pasture lands as a plant nutrient source and occasionally as a means of disposal (Whalen and Chang, 2001; Ferguson et al., 2005). Over 2.2 billion tons of animal manure is produced annually in the United States (Wright et al., 1998). There are increasing concerns with continuous manure application from confined animal feeding operations (CAFO) on environmental quality, due to limited land available for land application in some CAFO's. The high transportation costs usually result in manure being continuously applied in areas around the facilities above plant nutrient requirements (Whalen and Chang, 2001). When soil test phosphorus (STP) is sufficient for plant growth, any application of P greater than crop removal may result in soil P build up, and possibly eutrophication of surface water (Allen and Mallarino, 2006), thus degrading water quality. Understanding soil nutrient management and utilizing nutrient management plans will help alleviate this environmental concern. Manure contains organic matter and many essential plant nutrients that impact soil properties, such as STP, soil nitrate, soil pH, and soil organic matter (SOM). When manure is utilized as a nitrogen (N) source, N availability from different types of manure is poorly understood.

Manure applied on an N basis generally results in more P than crops need. Manure has N to P ratios that are smaller than the ratios of crop uptake, e.g., 2:1 for poultry litter but about 8:1 for most crops and pastures (USDA, 2001). Feedlot manure have been reported as having N to P ratios of 2.6:1 where winter wheat has N to P ratios of 4.5:1 (Eghball and Power, 1999). Over time manure application based on crop N needs will lead to a buildup of P in soil (Sharpley et al., 1999; Koopmans et al., 2007). Consequently, environmental concerns increase with the application of manure or any other source of P due to potential loss of P from high STP areas to water bodies. The risk to water quality is affected by tillage practices, ground cover, and soil texture. Studies have shown that conventional tillage or coarser soils will have a greater potential of P loss as compared to low-intensity grasslands or finer soils (Whalen and Chang, 2001). On the other hand, application of manure with high organic matter contents will increase SOM and aggregate stability and potentially reduce soil erosion and total phosphorus losses (Andraski et al., 2003).

Many studies have shown continuous application of manure result in increasing levels of STP (Whalen and Chang, 2001; Ferguson et al., 2005; Allen and Mallarino, 2006). Other studies have shown that increases in runoff P are directly related to elevated concentrations of P in soil (Sharpley, 1995; Pote et al., 1999; Cox and Hendricks, 2000; Torbert et al., 2002; Daverede et al., 2003; DeLaune et al., 2004; Kleinman et al., 2004; Davis et al., 2003; Zhang et al., 2006). The rate of STP increase varies depending on application rates and soil properties. Researchers have found that STP increases linearly with the amount of P in the manure applied, but the rate of increase are different with different soil types (Sharpley, 1995: Cox and Hendricks, 2002; Allen and Mallarino, 2006). A soil with lower clay content and extractable calcium concentrations will have higher STP concentrations as opposed to a soil with higher clay contents (Allen and Mallarino, 2006). The texture of a soil also affects P saturation point as reported by Whalen and Chang (2001); a clayey textured soil could receive 40 kg P Ha^{-1} annually from sewage effluent for 120 to 153 years before it could be saturated with P. A study conducted by Ferguson et al. (2005) indicated that surface P concentration of 500 mg kg^{-1} as not of concern for their site due to landscape position. Land position, proximity to surface water, and land management practices along with soil texture determine the potential of P loss to water bodies. Thus better understanding of P accumulation in soils is needed to better understand manure land management and to minimize the impact of agriculture on the environment.

Manure has been demonstrated to increase or stabilize soil pH over time (Boman et al., 1996; Sharpley et al., 2004; Koopmans et al., 2007). The process of land applying manure will raise the pH of acidic soils due to the dissolution of $CaCO_3$ and the consumption of hydrogen ions in solution (Koopmans et al., 2007). Manure has been shown to increase soil pH in sandy soils to a depth of 50-cm when compared to a control (Koopmans et al., 2007). Two sites in eastern Oklahoma were shown to increase soil pH by 1.5 units from poultry litter application and 0.4 units from swine slurry application over a period of 12 and 10 years, respectively (Sharpley et al., 2004). Long term data from the Magruder wheat experiment plots located in Stillwater, Oklahoma confirm the liming effect of manure (Boman et al., 1996). There was a significant difference in soil pH between the manured and the check treatments in 1937 when pH was first measured 45 years in the study (Boman et al., 1996). The pH difference between the plots remained in 1992, 100 years after the study initiation. In most agricultural setting the increase of pH in an acidic soil would be considered a significant benefit.

Soil organic matter is another component that can be affected by manure application. According to Koopmans et al. (2007) SOM contents were increased by manure treatments compared to the control. Their study was a long term experiment that was superimposed onto a grass field where the soil had not been disturbed by tillage. Data from the Magruder experiment indicates that organic matter will gradually decline under conventional tillage. When the experiment was initiated in 1892 the SOM level was 3.58%, by 1999 the SOM of the manure and check treatments had decreased to 1.60% and 1.17%, respectively, but manure additions slowed the rate of SOM decline (Davis et al., 2003), and maintained a better soil quality.

Animal manure is a good source of N for crops and forages. However, one problem associated with manure is that the amount of plant available N varies from season to season. The N availability of manure is impacted by the source of manure and the coinciding environmental conditions during the growing season. The current process of predicting N availability is generally based on an assumption rather than a measurement, thus it is not always accurate. For example, N availability during the first year is often assumed to be 50-70% by Oklahoma State University (Zhang, 2007). Additionally, the N availability between sources of manure is often different. For instance, poultry litter has a higher amount of N mineralized (Preusch et al., 2002) than that of beef feedlot manure (Egball, 2000). There may even be differences in the amount of N mineralized from the same manure when fresh or composted. For example, a fresh poultry manure sample had a range of N mineralization rate of 42% to 64%, whereas mineralization in the composted poultry manure ranged from 1% to 9% (Preusch et al., 2002). The amount of N mineralized was affected by manure management and the length of application (Shi et al., 2004). Rainfall and soil moisture have an effect on the dynamics of soil microbial communities and, thus rate of N mineralization.

Estimations are commonly used to determine the amount of mineralizable N that is available from manure in the year of application and subsequent years. Estimates are generally based on an average of mineralizable N from manure, but it is difficult to account for the temporal variability from season to season and from year to year. For example, the first-year estimates were compared to a recovery method using N^{15} to validate the accuracy of the projected N release at the University of Wisconsin (Munoz et al., 2004). The N^{15} method did provide reliable results, but it is impractical for producers. Isotopes can help in determining the amount of mineralized N from manure under controlled environments but it does not adequately account for in-season differences which is a significant factor.

An in situ resin method, which determined the amount of mineralized N during the growing season, was used to assess N availability from beef cattle feedlot manure in Nebraska (Eghball, 2000). However, the method was very time consuming and expensive to perform, and was not easily adaptable for producers to utilize (Eghball, 2000). Therefore, a more reliable and convenient technique is needed for producers to properly manage N in agricultural fields where manure is used as the nutrient source.

Optical sensors have been developed by scientists at Oklahoma State University to predict in-season N needs of winter wheat and other crops (Taylor et al., 1998). This technology uses spectral radiance in green (570 ± 6 nm), red (671 ± 6 nm) and near infrared (NIR) (780 ± 6 nm) wavelengths to determine normalized difference vegetation index (NDVI). The NDVI is calculated based on reflectance at red and NIR region using the following equation: $\text{NDVI} = (\text{NIR} - \text{red})/(\text{NIR} + \text{red})$ (Taylor et al., 1998). It has been demonstrated that NDVI measurement in winter wheat can provide a reliable prediction of biomass and N uptake (Raun et al., 2001), so that topdress N can be accurately prescribed.

Similar to managing commercial N fertilizers, we think optical sensors have the potential to determine the amount of N that is mineralized from manure for crops during the growing season by comparing NDVI from organic residue amended portion of the field with that of an N-rich strip. To our knowledge, no research has been done for this purpose. Using a response index (RI) that is derived from the NDVI of each treatment compared with the NDVI on a non-N limited strip should assist in determining the additional N needed to achieve the yield goal. An N-Rich strip is "a strip at a rate where N would not be limiting throughout the season" (Raun et al., 2002). By comparing the RI's using optical sensors, in-season N mineralization predictions may be obtained. These predictions may be used by producers to get the full effect of manure by allowing in season supplements of the proper amounts of N. Overall, the development of the optical sensor will allow it to be a convenient tool to producers for managing inorganic and organic source of N.

The Illinois soil N test (ISNT) was developed to help determine mineralizable N in soils that are unresponsive to N application (Mulvaney et al., 2001). The ISNT method is a short incubation analysis of soil in 2 *M* NaOH to determine total hydrolysable N (THN). The THN consists of exchangeable NH_4-N and amino sugar N. The amount of amino sugar N is the difference between THN and exchangeable NH_4-N. Soils that were unresponsive to N applications were found to have high levels of amino sugar N concentrations (Khan et al., 2001). Thus, this method may also serve as a valuable too for N management in manured fields.

Cropping systems that receive organic sources of fertilizer have been shown to maintain soil SOM as compared to commercial fertilizers (Marriott et al., 2006). Organic sources such as animal manure will potentially lead to an increase in N mineralization potentials (Marriott et al., 2006). It has been shown that regular manure application enriches soil with available N so crops may not respond to commercial fertilizer applications. Through the addition of organic residues microbial communities thrive taking up organic N in the form of amino acids from the decaying residues. Microbial biomass has a large amount of organic N present in the cell walls in the form of polymers of amino acids. These N compounds are prone to mineralization. It has been demonstrated that N of amino sugar in soils is quickly mineralized (Mengel, 1996). The ISNT could be a tool in determining if manured sites will be responsive to additional N application.

OBJECTIVES

The objectives of this study were to evaluate the effects of long term manure application on soil pH, soil test P, soil residual N and soil organic matter, wheat grain yield, and quality; and to evaluate N availability assumptions of land applied manure to winter wheat during the growing season using conventional soil test, an optical sensor and the ISNT.

MATERIAL AND METHODS

Experimental Site and Treatments

A long term manure research study was initiated in October 2000. Winter wheat (*Triticum aestivum* L.) was planted on a Norge loam soil (fine-, mixed, active, thermic Udic Paleustolls) (NRCS, USDA 2001) at the EFAW Research Station, Stillwater, OK. The experimental site has mean annual temperature of 16°C and mean annual precipitation of 86 cm.

Ten treatments were randomly placed in blocks with 3 replications (Figure 1). Continuous winter wheat has been planted every fall of the long term experiment with a yield goal of 3.36 Mg ha^{-1} (50 bu ac^{-1}). This yield goal traditionally requires 112 kg N ha^{-1}. Treatments were designed to determine if three different types of manure yielded the same as urea (46-0-0) on an N bases and to monitor STP levels as a result of applying manure on an N basis. Manures and diammonium phosphate (DAP,18-46-0) were applied at STP recommendations until STP levels were greater than 32.5 mg kg^{-1} then they were applied at calculated crop P removal rates (9.8 kg ha^{-1}), then urea was added to achieve a total of 112 kg N ha^{-1} available N. An N based treatment with urea only, a DAP treatment applied on a P basis only, and a control were implemented. The treatments included: dairy manure (DM), poultry litter (PL), and feedlot manure (FM) on N basis; 3 types of manure P basis plus urea [dairy manure (DM+), poultry litter (PL+), and feedlot manure (FM+)]; DAP (18-46-0) plus urea (DAP+); commercial fertilizer N based; 112 kg N ha^{-1} from urea; commercial fertilizer P based only 22.4 kg P_2O_5 ha^{-1}

from DAP; and a control (Table 1). Manure treatments were applied with an assumption of 70% available N. Resulting in 109 Mg ha^{-1}, 32.8 Mg ha^{-1}, and 77.6 Mg ha^{-1} of total amount manure (wet weight basis) applied from dairy manure, poultry litter, and feedlot manure, respectively from 2000 through 2006. The amount of manure applied each year varied according to manure analyses. Typical nutrient contents of manure used are shown in Table 2. Manure and commercial fertilizers were applied pre-plant and incorporated before planting.

In October of 2006 application of manure and fertilizer was modified to account for soil residual nitrate-N in the surface soil (0-15 cm). Rates were calculated for DM, PL, and FM treatments by subtracting the mean soil nitrate N of each treatment from the total amount of N needed (112 kg N ha^{-1}). The DM+, PL+, FM+ and DAP+ treatments only received P rates of manure or DAP, with no additional N. The N based urea treatment received the full amount of N as urea (112 kg N ha^{-1}), which was also served as an N-rich strip for the sensor.

Soil Sampling and Analysis

Soil samples were collected from all plots individually post harvest in August of 2001, 2002, 2003, 2005, and 2006. Fifteen cores at a depth of 0-15 cm were obtained per plot and combined to make a composite sample**.** Soil samples were oven dried at 65°C and ground to pass a 2-mm sieve. Mehlich 3 extractable P (M3P) was determined by shaking 2.0-g of soil and 20 mL of M3 solution (0.2 M CH_3COOH, 0.25 M NH_4NO_3, 0.015 M NH_4F, 0.013 M HNO_3, and 0.001 M EDTA) in 50 mL centrifuge tubes for 5 min on an end-to-end shaker (150 opm) (Mehlich, 1984). The samples were filtered (Fisherbrand P4 filter paper) and analyzed colorimetrically for P (Murphy and Riley, 1962). The M3 extract was also analyzed for plant available K (Helmke et al., 1996) using an inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (Spectro CirOs, Fitchburg, MA). Soil pH was measured in a 1:1 soil to deionized water suspension with a combination electrode (Thomas, 1996). Ammonium N (NH_4-N) and nitrate N (NO_3-N) were extracted with 1.0 *M* KCl (shake time of 30 min) and quantified using a Lachat Quickchem 8000 automated flow-injection analyzer (Zellweger Analytics, Milwaukee, WI) (Mulvaney, 1996). Total N and organic carbon was determined by dry combustion using a LECO CN 2000 or Truspec CN Analyzer (LECO Corporation, St. Joseph, MI) (Bremner, 1996; Nelson and Sommers, 1996). Soil organic matter is calculated by multiplying soil organic carbon by a factor of 1.724 (Nelson and Sommers, 1996).

The Illinois soil nitrogen test (Khan et al., 2001) was conducted on samples collected in August 2006 to evaluate mineralizable N. An aliquot of 10 mL of 2 *M* NaOH was dispensed into a one pint mason® jar containing 1 g of soil. A Petri dish with 5 ml of boric acid-indicator solution was attached to the lid and placed tightly into the mason jar. Jars were heated on a hot plate to 48-50°C determined by placing a thermometer in a beaker with 100 mL of deionized water in the center of the plate for 5 hours. Samples were removed from the hot plate and the boric acid-indicator solution was dispensed with 5 mL deionized water. Samples were titrated with 0.01 *M* H_2SO_4 to a pale red endpoint or to a pH endpoint of 4.5. The amount of N liberated (amino sugar N and NH_4-N) was calculated from the volume of 0.01 *M* H_2SO_4 dispensed (1 mL of 0.01 *M* H_2SO_4 equals to 280 μg N mL^{-1}) (Khan et al., 2001).

Optical Sensing

Each plot was sensed 5 times from Feekes stages 2-6 (Large 1954) in the spring of 2006 and 2007 with an NTech hand held Green Seeker Sensor® (NTech Industries, Inc.). Feekes growth stage 5 has been shown to be an optimum stage of growth for in-season yield prediction (Mullen et al., 2003). In both years, the urea treatment was utilized as the N-Rich strip since the full rate of N (112 kg N ha^{-1}) plus the residual soil nitrate was considered adequate for the highest yield achievable in the region, or non-N limiting. Normalized difference vegetation index (NDVI) readings of all treatments were compared with the N-Rich strip to determine the amount of additional N needed for the yield potential predicted using an algorithm (Raun et al., 2005) developed for winter wheat in Oklahoma, which served as an indirect measurement of N mineralized from manure.

Harvest and Grain Protein Analysis

Plots were harvested using a self-propelled Massey Ferguson 8XP combine with a 1.8 m header. The harvested area was 1.8 m by 9.1 m (16.4 m^2). A Harvest Master yield-monitoring computer installed on the combine was used to record yield and grain moisture data for each plot. Sub-samples of grain were collected from individual plots for total N analysis or protein. Grain samples were dried in a forced air oven at 66°C, ground to pass a 140 mesh sieve (100 μm), and analyzed for total N (Schepers et al., 1989) using a Carlo-Erba NA 1500 automated dry combustion analyzer from 2001 to 2005. Grain samples from 2006 were analyzed for total N using a LECO Truspec CN automated dry combustion analyzer. Wheat grain protein was calculated by multiplying total N by a factor of 5.7 (Woolfolk et al., 2002).

Statistical Analysis

Statistical analyses were performed utilizing procedures in SAS (SAS Inst., 2001). Means separations for main effects through time and across treatments were performed using the Duncan's multiple range tests. Contrast was also conducted for group separations. Some significant interaction effects are displayed graphically to better identify these interactions.

RESULTS AND DISCUSIONS

Effect of Manure Application on Soil Properties

Soil pH

The average initial pH of the site was 5.8. Application of PL, DM, and FM did not significantly affect ($p > 0.05$) soil pH in the first year of application or over time (Table 3). There was no significant difference ($p > 0.05$) in soil pH between treatments of PL, DM, and FM when compared to the control in 2001 and 2006. The application of manure was found by Whalen et al. (2000) to increase or maintain soil pH. This can be attributed to the buffering effect of bicarbonates from manure (Whalen et al., 2000). Manure application does add calcium (Ca) and magnesium (Mg) to the soil, which is greater than crop removal of these cations. The 2006 PL grain yield removed 1.18 kg Ca ha^{-1} and 3.25 kg Mg ha^{-1}, while 148 kg Ca ha^{-1} and 21.3 kg Mg ha^{-1} was applied from the manure application. The combination of manure buffering effects with the addition of Ca and Mg did in fact contribute to maintaining an acidic soil pH, but did not increase pH for this study.

Soil pH was significantly decreased the first year of application as well as over time ($p < 0.05$) by the urea treatment. Similarly, the application of PL+, DM+, FM+ and DAP+ resulted in a significant decrease ($p < 0.05$) of soil pH during the first year and over time. This is attributed to the processes of urea hydrolysis ($CO_2\ (NH_2)_2 + 3H_2O \rightarrow 2NH_4^+ + 2OH^- + CO_2$) (Rodriguez et al., 2005) and nitrification (biological oxidation of NH^+_4 to NO^-_2 and NO^-_3) (White et al., 2003) results in the release of hydrogen ions into the soil solution; thus leading to a pH decrease, since all the P-based manure treatments received N as urea. Additionally, the removal of cations with the crops could also result in a soil pH decrease for plots that did not receive manure. Apparently the effect of urea hydrolysis and nitrification is greater than the buffering effect from dairy, poultry litter, and feedlot manure applied on a P basis, thus resulting in soil pH decrease as shown. The addition of DAP by itself did not significantly affect soil pH (Table 3).

In 2006, there were highly significant differences ($p < 0.0001$) in soil pH for the N based manure (DM, PL and FM) versus other treatments with urea added (DM+, PL+, FM+, DAP+ and Urea). The soil pH was maintained by the N based manure treatments over time, where as soil pH declined over time for the treatments where urea was added. This confirms the liming benefits of manure in acid soils. However the liming benefit was consumed by urea hydrolysis and nitrification when manure was applied on a P basis with the addition of urea.

Soil Test Phosphorus

Dairy manure treatment did not significantly affect M3P ($p > 0.05$) concentrations in soil during the first year of application as compared to the control nor over time (Table 4). Conversely, the application of FM significantly increased ($p < 0.05$) M3P during the first year of application compared to the control (Table 4), but did not show an increasing trend thereafter. This is not consistent with the total amount of P_2O_5 applied over the course of the experiment (1,172 P_2O_5 kg ha^{-1}, DM; 872 P_2O_5 kg ha^{-1}, FM). However, the PL treatment did significantly increased M3P over time but did not significantly increase M3P during the first year of application (Table 4). Two long-term studies (10 years and 6 years, respectively) by Ferguson et al. (2005) and Andraski et al. (2003) showed a significant increase P is surface soils with feedlot and dairy manure applications, respectively, which is in contrary to what we found. This could be due to the greater application of feedlot manure by Ferguson et al. (2005) of 74 Mg ha^{-1} yr^{-1} and dairy manure by Andraski et al. (2003) of 90 Mg ha^{-1} yr^{-1} as apposed to our experiment where the total amount over 7 years of FM and DM applied were 77.6 Mg ha^{-1} and 109 Mg ha^{-1} respectively. This may also suggest the Norge soil from our experiment having different P fixing capacity from their soil.

The PL treatment resulted in an increase of approximately 52% in M3P from 2001 to 2003. The increasing trend of M3P is associated with the application of poultry litter on an N basis, resulting in an application of P that is greater than crop removal. A significant linear plateau relationship ($p < 0.0001$, $r^2 = 0.83$) was observed between M3P and accumulative P_2O_5 added in PL (Figure 2). There appears to be a plateau in M3P starting 2003 (i.e. M3P levels in years 2003, 2005 and 2006 were not significantly different from each other.) The plateau observed is inconsistent with data presented by Allen and Mallarino (2006) where STP increased linearly with continuous manure application. Manure rates for Allen and Mallarino (2006) were 112 to 168 kg total N ha^{-1} which is comparable to the PL treatment of 160 kg total N ha^{-1}(total N applied with 70% assumed N availability). It is unclear why STP stopped increasing for the PL treatment.

The DM+, PL+, and FM+ treatments did not significantly affect soil M3P ($p > 0.05$) during the first year of application compared to the control or over time (Table 4). Similarly the DAP, urea, and the DAP+ treatments had little effect on M3P during the course of the study (Table 4). This suggests adding P_2O_5 at the crop removal rate would not result in fast soil P buildup.

The N based manure treatments (DM, PL, and FM) had a higher STP ($p < 0.0001$) than all other treatments as a group for 2006 indicating that N based manure application, did have an effect over time, but no trend was observed. A nutrient management plan that considers both N and P should be recommended to producers in order to minimize P build up and loss from manured fields.

Soil Nitrate Nitrogen

The DM, PL, and FM treatments did not significantly increase soil NO_3-N during the first year of treatment as compared to the control (Table 5), but PL had a significant ($p < 0.05$) increase in 2006 over the previous years. Additionally, significant differences ($p < 0.05$) occurred between the DM+, PL+, FM+, DAP+, and the urea treatments compared to the control in 2006 with the control being lower in soil NO_3-N. However, treatment differences did not exist in 2001. For the PL treatment, significant differences were observed between years in soil NO_3-N and a significant linear relationship ($r^2 = 0.95$) existed between soil NO_3-N and time (Figure 3). A study conducted by Roth et al. (1992) concluded that poultry manure had the greatest potential of accumulating soil NO_3-N. Even though poultry manure has been documented to accumulate soil NO_3-N no justification has been discussed. Significant differences in soil NO_3-N between years were displayed in the DM and FM treatments, but soil nitrate accumulation relationships over time were not significant (Table 5). Ferguson et al. (2005) found that application of feedlot manure accumulated soil NO_3-N over a period of 10 years, but their application rate of manure on a dry basis had a mean of 74 Mg ha^{-1} applied annually, and was much greater than our FM treatment where a total of 77.6 Mg ha^{-1} was applied over a period of 7 years.

Soil Organic Carbon

Soil organic carbon determined in 2002, 2003, 2005, and 2006 is presented in Table 6. In general, SOC concentration decreased with respect to time for all treatments. This trend reflects the fact that continuous winter wheat was planted on land that was originally undisturbed grassland. Additionally, this site received at least two tillages per year. Tillage took place after harvest to incorporate the wheat stubble and after application of manure and fertilizer prior to planting. Soil organic matter decreases of 30% to 60% are typical where native ecosystems have been disturbed due to tillage (Grandy and Robertson, 2006). The decrease in SOM is due to increased aeration and altered microbial communities and functions (Grandy and Robertson, 2006), thus releasing organic carbon in the form of CO_2 back into the atmosphere. There is documented evidence from Davis et al. (2003) that manure application slowed down the rate of SOM decrease in Magruder plots which have been under cultivation at Oklahoma State University since 1892. It is possible that our study may need to be conducted longer before a significant effect can be seen in the manure treatments.

Effect of Manure Application on Wheat Production

Wheat Grain Yields

No treatment differences were observed for winter wheat grain yields of the average over the last three years (2004 through 2006) of the study (Table 7). It is not clear why the control (received no fertilizers) was not different from other treatments. This will be further discussed later in the Residual N section. All treatments except DAP and control received 112 kg N ha^{-1} of potentially available N, either from manure or commercial fertilizer. Analysis of the yield data indicates the assumption of 70% N available from manure was probably valid since no significant differences ($p > 0.05$) occurred between manure and commercial N treatments. A long-term manure study conducted by Ferguson et al. (2005) resulted in manure treatments yielding higher corn silage yields than that of commercial N treatment. Their experiment applied manure with 35% available N assumptions for fresh manure and 25% available N assumptions for composted manure (Ferguson et al., 2005). Possibly, the actual N availability from their manure was higher than what they assumed for the higher yields achieved. In our experiment, the DAP treatment only received 8.7 kg N ha^{-1} due to the carry over of using DAP on a P removal basis and the control did not receive any source of applied N. The low amount of N applied in DAP and no N applied in the control should theoretically result in decreased yields as compared to the other treatments. However, unintentional nutrient cross contamination across treatments due to tillage equipment or runoff water may have resulted in higher than expected grain yields in the DAP treatment and control. Additionally, N may not be a limiting nutrient at this site or there is possibly an outside source of N that is becoming available for plant uptake, such as N from atmospheric deposition or from geese droppings. The geese droppings were deposited by geese that grazed on the wheat plants during the winter, resulting in applications of manure and N that was not accounted for.

Wheat Grain Protein

Unlike wheat grain yields, there were significant differences in the mean wheat grain protein concentrations ranging from 10.4% to 15.4% (Table 7). The control had the lowest grain protein content of 10.4%, which was significantly less ($p < 0.05$) than that of other treatments. This suggests some applied N contributed to increased protein although it did not increase yields. Subedi et al. (2007) found that wheat grain protein concentrations were higher when N was applied at a rate of 100 kg N ha^{-1} compared to treatments receiving no N. Because the Duncan's multiple comparison indicated a grouping of data for the manure treatments and the treatment with urea added, we decided to examine this further by performing contrasts. Comparing N-based manure treatments (DM, PL, and FM) with all other treatments receiving urea (DM+, PL+, FM+, DAP+, and Urea) revealed the former had significantly less ($p<0.01$) grain protein concentration than later. The lower grain protein in N based manure treatments (70% assumed N availability) could be due to an insufficient amount of available N during the flowering stage of winter wheat. Whereas treatments with urea added supplied more available N during winter wheat flowering. Woolfolk et al. (2002) found that N applications to winter wheat before or immediately after flowering may enhance grain total N. If protein concentrations were of importance for our study, then it might suggest that the 70% assumed N availability of manure is too high. Resulting in inadequate available N to winter wheat late in the growing season when N is need for higher grain protein concentrations. Ferguson et al. (2005) suggested a beef feedlot N availability of 35% while Preusch et al. (2002) reported poultry litter N availability ranging from 42% to 64%. This information would conclude that in-season determination of manure N availability is essential if quality and yields are desired.

NDVI and Residual Soil Nitrogen

Normalized difference vegetation index (NDVI) measurements that were taken in March of 2006 and 2007 and calculated RI's at Feekes 5 of winter wheat are presented in

Table 8. Treatments DM, PL, and FM were applied on an N basis with 70% assumed N availability before planting as discussed above, so we utilized an optical sensor to determine if additional N was needed to achieve maximum yield potentials in the case that N availability was affected by seasonal factors. The calculated RI is a relationship of NDVI from plants that are not N limited compared to NDVI from plants that are potentially N limited in the same field. That results in an RI value that potentially determines the percentage of yield decrease if no additional N is applied, unless the RI is =1 in which no response to additional N should possibly be observed. In 2006, the DM treatment resulted in an NDVI that was lower than the N-rich strip (Urea treatment) thus, implying that at sensing there was less N taken up by the wheat from the DM treatment. However, the RI for the site was 1.2 indicating that if N was added to the check there could potentially be an increase of 20% when compared to an N-rich plot. The sensor did validate the presumed N availability of the manure N-based treatments since there were no differences in yields but there were also no differences in all yields among all treatments. This could be due to the abundance of residual soil N.

The NDVI measurements taken in 2007 were higher than those in 2006 (Table 8), which is a result of different growing conditions between years (2007 was wetter than 2006). The N-rich strip (Urea treatment) had a greater NDVI (0.7437) than the DM treatment (0.6808). The response index for the site was 1.12, implying that if no additional N was applied to the control treatment it could possibly produce 12% less grain than the N-rich strip. On the other hand, the DM treatment did have an NDVI that was less than the control (Table 8). Thus, indicating that N availability from the DM treatment might be potentially less than the assumed 70% N availability application rate.

No yield data is available for the 2007 season at this time to conclude if the DM treatment did in fact produce lower grain yields. Since the DM treatment had NDVI's that indicated inadequate N available for plant growth up the time of sensing for both years and there was no decrease in yields for 2006. This would suggest a better understanding of residual soil N is needed to understand why no differences in yield occurred.

The ISNT was performed to determine amino sugar-N on the 2006 soil samples to investigate the lack of responses in wheat grain yields for past years. Soil amino sugar-N contents of all treatments are presented in Table 9 along with soil NO_3-N and NH_4-N contents. In general, there was no difference in amino sugar-N concentrations and amino sugar-N plus soil NO_3-N and NH_4-N among all treatments. The ISNT was developed to identify soils that are unresponsive to N application. It determines the amount of potentially mineralizable N that could become plant available (Mulvaney et al., 2001). For corn production in Illinois, amino sugar-N < 200 mg kg^{-1} is considered responsive to N application and amino sugar-N > 250 mg kg^{-1} is considered nonresponsive (Mulvaney et al., 2001). Since dry land winter wheat grain yields in Oklahoma are considerably less than corn grain yields in Illinois, the residual soil N amounts in the form of amino sugar-N in this study could possibly be at levels that are unresponsive to N application. Especially, when mean soil NO_3-N and NH_4-N levels for all treatments account for 54% of N needed to produce 3.36 Mg ha^{-1} (50 bu ac^{-1}) of winter wheat. This may partially explain why grain yields were not different among treatments. The high amount of residual N is possibly due to the continuous reduction in SOM resulting in released available N, carrying over of N from adjacent plots stemming from soil tillage, or from an outside source such as geese droppings which were observed on the plots during most years. A fence was constructed in the fall of 2006 immediately after planting to prevent the interference from geese dropping on the study.

Other evidence that could validate soil residual N influence on wheat grain yields is that treatments DM+, PL+, FM+, and DAP+ (P based treatments) did not receive any additional N from urea in the fall of 2006 but also had similar amounts of available or potential available N. Normalized difference vegetative index for 2007 indicated N was not limited up to the time of sensing for these P based treatments, suggesting that soil residual N could be sufficient for winter wheat grain production for this site. Grain yield data for 2007 should be available to support this suggestion.

CONCLUSION

Confined animal feeding operations are commonly found throughout different regions in Oklahoma. Long-term N based manure applications did maintain soil pH of an acidic Norge soil over this 7 year study. This may be good news for regions with acid soils resulting from intensive production. Whereas manure P and commercial P based applications receiving additional N in the form of urea did not maintain soil pH but in fact decreased soil pH by approximately 0.4 units. Manure application does create a viable option for Oklahoma wheat producers as a nutrient source who also observes decreased soil pH due to commercial fertilizer use and base nutrient removal by wheat grain.

However, continuous manure application has been documented to increase M3P in soils creating an environmental concern to water quality. Our study did observe a M3P increase from N-based poultry litter application in the first 3 years but did not increase over time thereafter. The N-based manure treatments did result in higher M3P versus the P-based treatments as a group. Providing valuable information to researchers and producers who want to apply manure where water quality is a concern without increasing M3P.

Average grain yields were not different among treatments, suggesting that residual soil N might be a contributing factor to the lack of responsiveness of wheat grain yields to N applications. The Green Seeker Sensor® did not predict N availability from manure, but did reveal no top-dress N was needed. Additional research is needed at a different site where residual soil N is not a concern, to further evaluate the feasibility of using sensors to better manage manure nitrogen.

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Table 1. Treatments and rates of long-term manure application to a continuous winter wheat trial.

Treatment	Application Basis	Fertilizer Rate and Source
DM	N based	112 kg N ha^{-1} Dairy Manure
PL	N based	112 kg N ha^{-1} Poultry Litter
FM	N based	112 kg N ha^{-1} Feedlot Manure
DM+	P based + Urea	22.4 kg P_2O_5 ha^{-1} Dairy Manure, Urea to 112 kg N ha^{-1}
PL+	P based + Urea	22.4 kg P_2O_5 ha^{-1} Poultry Litter, Urea to 112 kg N ha^{-1}
FM+	P based + Urea	22.4 kg P_2O_5 ha^{-1} Feedlot Manure, Urea to 112 kg N ha^{-1}
DAP+	P based + Urea	22.4 kg P_2O_5 ha^{-1} DAP, Urea to 112 kg N ha^{-1}
Urea	N based	112 kg N ha^{-1} Urea
DAP	P based	22.4 kg P_2O_5 ha^{-1} DAP
Control	Control	Control

Table 2. Major nutrient contents of three different manure sources applied to Norge soil.

Manure	Analysis Results (g kg^{-1})					
	2005			2006		
	TN	TP	TK	TN	TP	TK
Dairy	13.8	4.6	7.9	7.5	4.6	7.9
Poultry	41.2	17.0	20.8	34.8	12.3	23.8
Feedlot	16.5	4.6	10.0	17.8	5.7	13.3

Table 3. Comparison of mean soil pH under annual manure and fertilizer treatments applied to the Norge soil from 2001-2006.

Treatment	2001	2002	2003	2005	2006
DM	5.4a[†]AB[‡]	5.3a	5.3a	5.3a	5.3aA[‡]
PL	5.4aAB	5.4a	5.4a	5.4a	5.3aA
FM	5.5aA	5.4a	5.5a	5.5a	5.5aA
DM+	5.4aAB	5.2ab	5.1b	5.1b	5.1bB
PL+	5.3aB	5.2ab	5.2ab	5.3ab	5.0bB
FM+	5.3aB	5.2ab	5.1ab	5.1ab	4.9bB
DAP+	5.3aB	5.1a	4.9b	5.1ab	4.9bB
U	5.3aB	5.2ab	5.1ab	5.1ab	4.9cB
DAP	5.4aAB	5.4a	5.3a	5.4a	5.3aA
Control	5.5abA	5.5ab	5.6a	5.4b	5.4bA

[†] Mean pH values in the same row with the same smaller case letter are not significantly different at an alpha level of 0.05.

[‡] Mean pH values in the same column with the same upper case letter are not significantly different at an alpha level of 0.05.

Table 4. Comparison of mean Mehlich-3 phosphorus values (mg kg^{-1}) for different treatments applied to the Norge soil from 2001-2006.

Treatment	Soil Test P					P_2O_5 Applied ($kg\ ha^{-1}$)
	2001	2002	2003	2005	2006	
DM	39a[†]BCD[‡]	42.5a	47.0a	46.5a	48.5aBC[‡]	1172[§]
PL	49.5cB	56bc	75.0ab	78.5a	78.5aA	979
FM	67.5abA	57.5b	64.5b	73.0a	56.0bB	872
DM+	42.5aBC	37.5a	35.0a	37.0a	36.0aDEF	134
PL+	33.0aD	35.0a	34.0a	40.0a	39.0aCDEF	134
FM+	41.0aBCD	43.5a	49.0a	38.5a	43.5aCD	134
DAP+	41.0aBCD	34.0a	36.5a	40.0a	39.0aCDE	134
U	30.5aCD	35.5a	33.5a	35.5a	30.5aEF	0
DAP	41aBCD	43.5a	44.5a	48.5a	47.5aBDC	134
Control	38.5aBCD	30.5a	28.0a	33.5a	28.0aF	0

[†] Mean M3P values in the same row with same lower case letter are not significantly different at an alpha level of 0.05

[‡] Mean M3P values in the same column with the same upper case letter are not significantly different at an alpha level of 0.05

[§] Total amount of P_2O_5 applied

Table 5. Comparison of mean soil nitrate nitrogen (mg kg^{-1}) levels for different treatments applied to the Norge soil from 2001-2006.

Treatment	2001	2002	2003	2005	2006
DM	11a[†]B[‡]	17ab	21a	16ab	17abABCD[‡]
PL	13cAB	15c	20b	20b	24aA
FM	18abA	19ab	23a	21a	14bBCD
DM+	12aB	20a	20a	14a	19aABC
PL+	10cB	21a	17ab	15bc	19abABC
FM+	13bB	20ab	23a	16ab	22abAB
DAP+	12aB	18ab	23a	15ab	22baAB
Urea	12aB	19a	16a	15a	20aABC
DAP	11aB	14a	18a	15a	12aCD
Control	15aAB	13a	13a	15a	10aD

[†] Mean NO_3-N values in the same row with same lower case letter are not significantly different at an alpha level of 0.05.

[‡] Mean NO_3-N values in the same column with same upper case letter are not significantly different at an alpha level of 0.05.

Table 6. Comparison of mean percent soil organic carbon (SOC) levels for different treatments applied to Norge soil.

Treatment	2002	2003	2005	2006
DM	1.45a[†]A[‡]	1.28bA	1.09cA	1.17bcA
PL	1.14bB	1.27aA	1.14bA	0.99cABC
FM	1.28aAB	1.28aA	1.11abA	0.91bC
DM+	1.28abAB	1.37aA	1.12abA	0.93bBC
PL+	1.26aAB	1.35aA	1.06aA	0.97aBC
FM+	1.35aAB	1.38aA	1.11bA	1.12bAB
DAP+	1.24aAB	1.28aA	1.02abA	0.96bBC
Urea	1.08bB	1.35aA	1.07bA	0.95bBC
DAP	1.26abAB	1.35aA	1.09abA	0.99bABC
Control	1.28aAB	1.30aA	1.14aA	1.06aABC
Mean[§]	1.26	1.32	1.10	1.01

[†] Mean SOC values in the same row with same lower case letter are not significantly different at an alpha level of 0.05.

[‡] Mean SOC values in the same column with same upper case letter are not significantly different at an alpha level of 0.05.

[§] Mean SOC values for all treatments.

Table 7. Comparison of mean grain yield (2004 through 2006) and mean grain protein (2004 through 2006) for the different treatments applied to the Norge soil.

Treatments	Mean Grain Yield ($Mg\ ha^{-1}$)	Mean Grain Protein (%)
DM	3.09a[†]	13.2ab[‡]
PL	3.12a	13.9ab
FM	3.01a	13.9ab
DM+	3.05a	15.0a
PL+	3.17a	14.9a
FM+	3.07a	15.4a
DAP+	3.11a	15.1a
Urea	3.09a	14.8a
DAP	2.84a	12.3b
Control	2.66a	10.4c

[†] Mean grain yields in the same column with the same letter are not significantly different at an alpha level of 0.05

[‡] Mean grain protein in the same column with the same letter are not significantly different at a alpha level of 0.05

Table 8. Comparison of mean normalized difference vegetation index (NDVI) measurements and response index (RI) calculations at Feekes 5 growth stage of winter wheat under different treatments applied to the Norge soil.

Treatments	2006		2007	
	NDVI	Yield (Mg ha^{-1})	NDVI	Yield (Mg ha^{-1})[†]
DM	0.5841	3.26	0.6808	*
PL	0.6241	3.26	0.7890	*
FM	0.6102	2.94	0.7420	*
DM+	0.6097	2.96	0.7394	*
PL+	0.5758	3.11	0.7367	*
FM+	0.6407	3.28	0.7425	*
DAP+	0.6270	3.35	0.7355	*
Urea[‡]	0.6122	2.98	0.7437	*
DAP	0.5421	2.92	0.6963	*
Control	0.5445	2.55	0.6913	*
Adj. RI_{NDVI}[§]	1.2	-	1.12	-
$RI_{Harvest}$[¶]	-	1.17	-	*

[†] Yield data for 2007 was not collected.

[‡] Urea was used as the N-rich strip in 2006 and 2007.

[§] Adjusted in-season response index was determined by dividing mean NDVI at Feekes growth stage 5 from Urea by the Control. Adjustment made using the equation (RI_{NDVI} x 1.69) – 0.7.

[¶] Response index at harvest was determined by dividing the mean grain yield of Urea by the Control.

Table 9. Soil nitrate-N, ammonium-N and amino sugar-N measurements from soil samples collected in the summer of 2006.

Treatments	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	Amino sugar-N (mg kg^{-1})	Amino sugar-N + NO_3-N + NH_4-N (mg kg^{-1})
DM	19	5	141ab[†]	165a[‡]
PL	25	7	125ab	157ab
FM	15	5	115b	135b
DM+	21	5	133ab	159ab
PL+	21	10	144a	175a
FM+	23	8	145a	176a
DAP+	24	5	131ab	160ab
Urea	21	8	137ab	166a
DAP	12	8	143ab	163a
Control	11	6	144a	161a
Mean[§]	19	8	136	163

[†] Mean amino sugar-N values in the same column with the same letter are not significantly different at an alpha level of 0.05

[‡] Mean amino sugar-N + NO_3-N + NH_4-N values in the same column with the same letter are not significantly different at an alpha level of 0.05.

[§] Mean NO_3-N, NH_4-N, Amino sugar-N, and Amino sugar-N + NO_3-N + NH_4-N values for all treatments.

Rep 1	FM+	DM	DAP+	DM+	Control	Urea	DAP	FM	PL+	PL
Rep 2	DAP	PL+	FM+	Control	DM	PL	DAP+	Urea	DM+	FM
Rep 3	Control	DM	FM+	DAP+	DAP	FM	PL+	DM+	PL	Urea

Figure 1. The plot design of a long-term manure and fertilizer application on winter wheat. The experiment is located in EFAW near Stillwater, OK on a Norge soil. The individual plot size measure 4.9m x 9.1m.

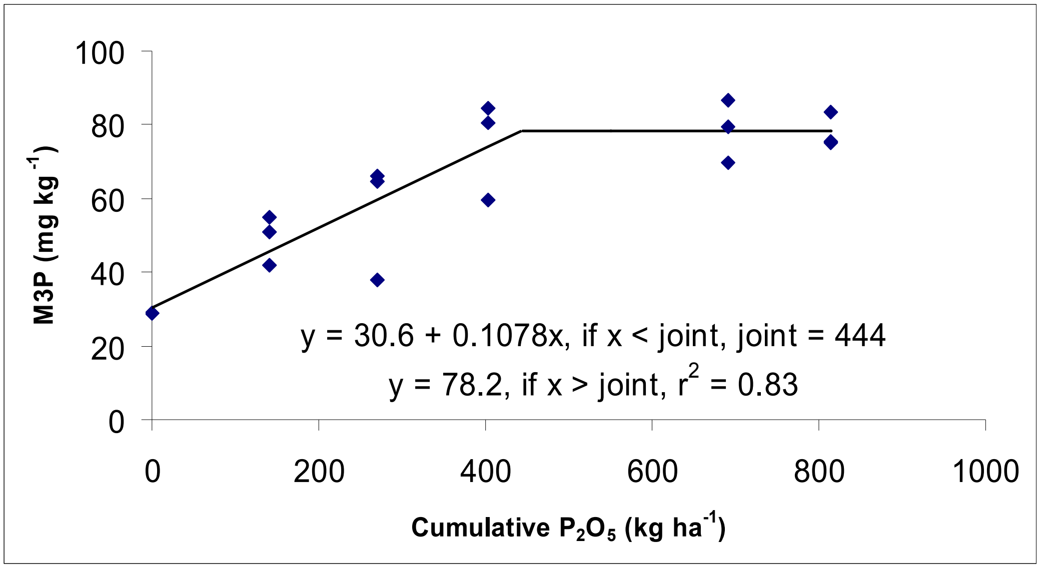

Figure 2. The relationship between soil M3P and the accumulative P_2O_5 added from poultry litter. ***$p < 0.001$.

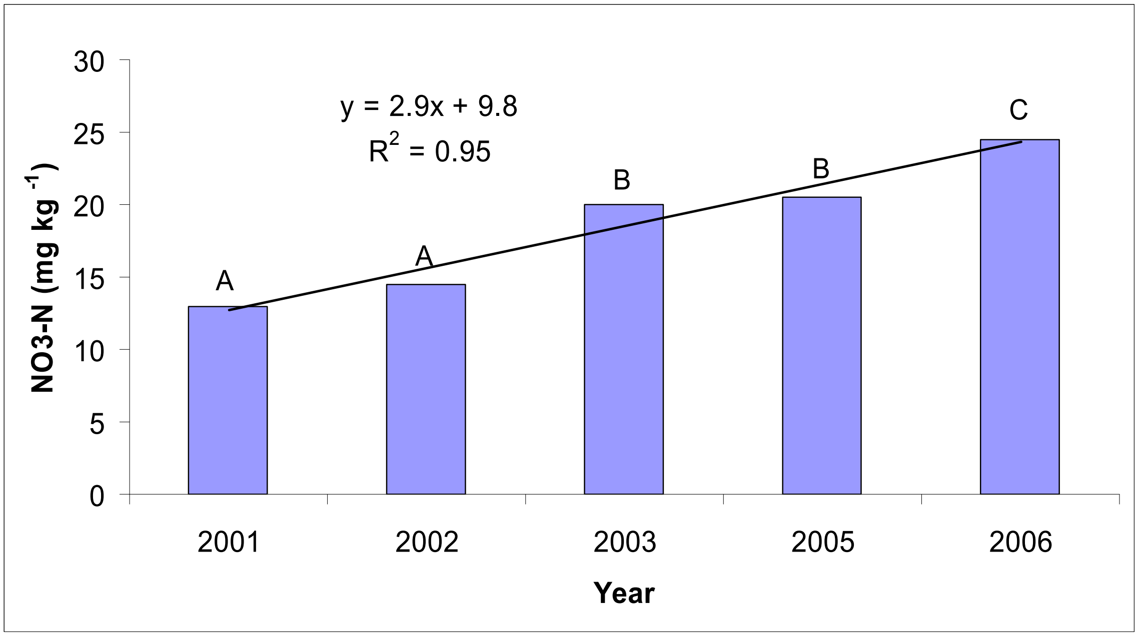

Figure 3. Preplant soil nitrate nitrogen from poultry manure application. Bars with the same letter are not significantly different at an alpha level of 0.05.

APPENDIX

Appendix A. Wheat grain yields (Mg ha^{-1}) for all years from long-term animal manure study.

	Treatment	2001	2002	2003	2004	2005	2006
REP 1	DM	3.34	2.86	4.07	4.12	2.29	3.73
	PL	2.53	2.80	4.54	4.05	1.84	3.48
	FM	2.52	2.48	4.69	3.32	2.66	3.76
	DM+	2.91	2.68	4.04	3.84	2.64	3.04
	PL+	2.30	2.65	3.82	3.97	2.30	2.97
	FM+	3.38	2.50	4.41	3.31	2.15	3.51
	DAP+	2.81	2.70	4.44	3.63	2.68	3.51
	Urea	1.94	2.55	4.09	3.90	3.11	3.43
	DAP	2.41	2.43	3.89	3.28	2.40	3.18
	Control	3.17	2.60	3.94	3.48	2.36	2.91
REP 2	DM	2.14	2.80	4.34	3.59	2.29	3.09
	PL	2.43	2.91	4.21	3.47	2.61	3.26
	FM	2.36	3.03	4.31	3.88	2.27	2.48
	DM+	2.61	2.98	4.36	3.71	2.74	2.93
	PL+	3.39	2.68	3.84	3.38	2.97	3.46
	FM+	3.39	2.02	4.21	3.25	2.82	3.20
	DAP+	2.69	2.25	4.21	3.04	3.18	3.49
	Urea	2.64	3.34	4.09	3.49	2.76	2.79
	DAP	3.10	3.16	4.21	3.84	2.36	3.15
	Control	2.35	2.86	3.74	3.24	2.25	2.47
REP 3	DM	2.39	2.86	3.87	3.84	1.91	2.96
	PL	2.88	3.11	3.82	4.10	2.16	3.03
	FM	2.71	3.13	3.94	3.91	2.20	2.58
	DM+	2.76	3.46	3.64	3.27	2.37	2.90
	PL+	2.94	2.83	4.26	3.98	2.59	2.89
	FM+	2.65	3.44	4.26	3.18	2.46	3.14
	DAP+	2.93	3.11	3.87	3.00	2.36	3.05
	Urea	2.63	2.53	3.25	3.28	2.33	2.72
	DAP	2.27	2.65	3.00	3.16	1.77	2.44
	Control	2.26	2.96	2.95	2.88	2.04	2.28
	Mean	2.69	2.81	4.01	3.55	2.43	3.06

Appendix B. Wheat grain protein (%) results for all years from long-term animal manure study.

	Treatment	2001	2002	2003	2004	2005	2006
REP 1	DM	15.1	13.5	14.0	13.1	16.0	13.7
	PL	15.4	14.1	13.4	11.7	16.7	14.1
	FM	15.9	15.4	14.0	14.2	15.6	13.6
	DM+	16.0	15.5	14.0	13.8	16.9	14.9
	PL+	16.2	15.9	13.8	13.0	16.5	14.9
	FM+	17.5	15.2	14.3	14.1	16.4	14.4
	DAP+	16.1	15.8	13.0	12.8	16.9	15.1
	Urea	15.1	14.4	12.7	13.1	16.3	14.7
	DAP	16.0	13.1	12.4	10.3	14.7	12.2
	Control	13.9	15.2	11.7		12.8	11.4
REP 2	DM	14.7	13.0	11.7	10.2	14.0	12.8
	PL	16.5	14.6	13.1	12.8	15.5	14.4
	FM	14.7	14.2	12.8	12.5	14.9	13.1
	DM+	15.6	14.7	15.2	15.0	16.3	15.1
	PL+	16.6	16.0	13.8	14.4	17.1	15.1
	FM+	16.2	17.3	15.1	15.0	18.1	14.7
	DAP+	16.4	17.3	14.9	14.8	16.9	14.9
	Urea	15.6	15.7	15.9	13.0	16.4	14.3
	DAP	14.8	15.4	13.5	10.5	15.0	12.8
	Control	14.1	13.3	11.9	10.5	13.0	12.1
REP 3	DM	13.3	13.4	12.4	10.7	15.3	13.4
	PL	15.4	12.9	10.6	10.2	16.3	13.3
	FM	15.2	14.2	13.3	11.6	15.0	14.4
	DM+	14.8	14.4	13.5	12.1	15.5	15.1
	PL+	15.2	13.9	14.5	12.1	16.5	14.6
	FM+	15.5	14.6	11.0	15.2	16.4	14.7
	DAP+	16.6	15.7	16.8	13.3	16.3	15.0
	Urea	16.0	17.6	17.2	13.7	16.3	15.0
	DAP	14.3	12.0	12.9	10.1	13.1	12.3
	Control	15.3	12.4	11.9	8.9	11.9	12.7
	Mean	15.5	14.7	13.5	12.5	15.6	14.0

VITA

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Master of Science

Thesis: DETERMINATION OF NITROGEN AVAILABILITY FROM ANIMAL MANURE AMENDED SOILS

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Title of Study: DETERMINATION OF NITROGEN AVAILABILITY FROM ANIMAL MANURE AMENDED SOILS

Pages in Study: 44 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Science

Scope and Method of Study: Manure has historically been applied to crop and pasture lands as a plant nutrient source based on nitrogen (N) needs. However, the amount of plant available N varies from season to season and has not been adequately addressed. This study was conducted to evaluate the effects of long term manure application on soil properties, winter wheat (*Triticum aestivum* L.) grain yield, and to determine the N availability of land applied manure. Three different manure sources (dairy, poultry, and feedlot) and commercial fertilizers were applied at rates of crop N or phosphorus (P) needs to a Norge loam soil (fine-, mixed, active, thermic Udic Paleustolls) at Stillwater, OK from 2000 to 2006. Soil samples were collected annually and analyzed for pH, nitrate, Mehlich 3 P, and organic carbon. Wheat grains were harvested every year for yield and protein. An optical sensor was utilized in 2006 and 2007 to determine if manure N based applications required additional N to achieve potential maximum yields.

Findings and Conclusions: Soil pH was maintained by N-based manure applications, but the addition of urea resulted in a decrease of approximately 0.4 pH units over time. Mehlich 3 P did not increase due to N based or P based treatments, except for poultry litter N based rate which increased by 52% in 2001 to 2003, but no increase was observed from 2003 on. Soil organic carbon (SOC) decreased in all treatments with time. Residual Soil N was generally the same for all the 2006 soil samples. Wheat grain yields were not affected by the sources of N over the extent of the study. The optical sensor did indicate that no additional N was needed. More research is needed to study the feasibility of using active sensors to manage manure nutrients.

ADVISER'S APPROVAL: Dr. Hailin Zhang