Long-term effects of land application of poultry manure on crop production, and soil and water quality under a corn-soybean rotation system in Iowa

by

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ABSTRACT

In recent years, the poultry industry has seen a steady growth in Iowa. With the increase in the broiler and egg industry, the public is concerned about the potential threat to environmental quality (surface and subsurface water and air quality) from increased volumes of poultry manure. Although the effect of poultry manure on crop production has been studied, its effects on water quality, under corn and soybean rotation, in Iowa have not been extensively studied. Therefore, a long-term study was initiated in 1998 to investigate the impacts of poultry manure on crop production and environmental quality (soil and water quality). This thesis will present the results of this eight year study (1998 to 2005) on land application of poultry manure on (i) crop yields and crop quality; (ii) subsurface drain water quality, and (iii) soil quality. Eleven experimental field plots of sizes varying from 0.14 to 0.4 ha were used in this study. Each field plot was drained by a single subsurface drain line passing through the center of the plot. These subsurface drain lines were intercepted at the end of the plot to collect water samples for water quality analyses. Corn and soybeans were planted in the same plot with corn on half of the plot and soybean on the other half. Only the corn side received the N fertilizer (poultry manure or Urea Ammonium Nitrate, UAN). Subsurface drain water samples were collected weekly during the growing season (March-October) and analyzed for NO_3-N and PO_4-P concentration. Soil samples were collected before planting and after harvesting each year and analyzed for NO_3-N and PO_4-P at 5 different depths of the soil profile. Corn stalk samples were also collected after harvest at the height of 20-25 cm from the ground and analyzed for nitrogen concentration. Two application rates of poultry manure (168 kg-N/ha and 336 kg-N/ha) and one application rate of UAN (168 kg-N/ha) were applied in split plot design with unbalance replications. A check

plot, not receiving any fertilizer (neither poultry manure nor UAN) during the study period, was also used to collect data on crop yields, and soil and water quality for comparison purposes. Statistically, data on corn and soybean yields were analyzed separately for all treatments. The overall results of this study for the eight year period (1998-2005) showed that applications at higher rates resulted in high NO_3-N and PO_4-P losses in comparison to lower application rates of poultry manure or UAN (168 kg-N/ha). Also, the results of this study showed that higher N application rates from poultry manure did increase corn yields significantly when compared to lower N application rates from either poultry manure or UAN. Plots receiving poultry manure at the same rates as those of UAN (168 kg-N/ha) resulted in significantly higher corn yields. This shows that poultry manure gives a better N fertilizer value for corn yields.

CHAPTER 1: GENERAL INTRODUCTION

Introduction

Since 2001, Iowa has become a leading state in the US not only in corn and soybean production but also in the poultry and swine industry as well. According to USDA-NASS (2005), the grain yield of corn and soybeans in Iowa were at 54.9 million tons and 14.5 million tons, respectively. Besides, there was a significant increase in the number of laying hens with approximately 44 million layers, producing 11.61 billion eggs (USDA-NASS, 2005). As a result of the stable development in poultry production, approximately 0.5 million ton of poultry manure has been released annually posing a potential threat to soil and water pollution. One of the common uses of poultry manure in Iowa is to utilize it as an organic N, P and K for crop production instead of chemical fertilizers. Basically, poultry manure has a higher total solid content than most other types of manures from animal species such as swine, beef, turkey, etc. and is considered a rich source of organic fertilizer for crop production. In the Midwestern States of the U.S.A. where 30% of the agricultural fields are drained using the subsurface drainage system, subsurface drain water is subject to contamination due to over application of manure in croplands (Tomer et al., 2003). The potential for contamination of ground and surface water through improper handling, disposal and land application of poultry manure is considerable because most poultry houses have a relatively small land base and transportation costs for poultry manure are high. Although poultry manure is one of the best organic fertilizers available, and is an extremely valuable resource, excessive land application rates can lead to nitrate and phosphorus leaching into groundwater, phosphorus (P) runoff losses into adjacent water bodies, and possibly cause elevated bacterial or pathogen levels in nearby lakes and rivers (Moore et al., 1995; Kanwar et al., 2005).

A long-term field research was initiated in Iowa in 1998, with the funding from the Iowa Egg Council, to get a better understanding of land application of poultry manure and collect science based data on crop yield, grain quality and water quality (Chinkuyu and Kanwar, 2001; Chinkuyu et al., 2002; Cheatham, 2003). This study investigated the effects of poultry manure and commercial fertilizer UAN at two application rates (168 kg-N/ha and 336 kg-N/ha) on crop yields, grain quality, and soil and water quality under a corn-soybean rotation system. In this study, an experimental design was developed where corn and soybeans were planted in the same field plot but N-fertilizer (UAN or poultry manure) was only applied on the corn side of the plot each year. Based on eleven field plots, each drained by an individual tile drain, researchers found that using poultry manure applications for corn-soybean rotation increased the crop yields significantly and reduced the nutrient losses to subsurface drain water at a lower N application rate (168 kg-N/ha) in comparison with other rates of poultry manure and UAN. However, the long-term effects of poultry manure on soil and water quality, and crops over long-term weather changes, especially rainfall patterns, had not been studied before. Therefore, this thesis research is based on this long-term study in determining the effects of poultry manure on soil and water quality under the corn and soybean production system in Iowa.

Research objectives

The overall objectives of this thesis research are to determine the long-term effects of poultry manure applications on (i) crop yields, grain quality, and corn stalk N uptake capability; (ii) subsurface drainage water quality (NO_3-N and PO_4-P); and (iii) soil quality

(NO_3-N and PO_4-P) over the eight year period (1998-2005) of this study. The outcome of this research could results in the adoption of a good agricultural practice for poultry producers in improving N management practices for crop production and improving water quality.

Thesis organization

This thesis has been divided into six main chapters: Chapter 1 is dedicated to the general introduction of the subject; Chapter 2 is the review of literature on the effects of poultry manure application on crop yield, and soil and water quality; Chapter 3 is a paper written on the long-term land application effects of poultry manure on crop yields under a corn-soybean rotation in Iowa; Chapter 4 is a paper written on the long-term effects of poultry manure on subsurface water quality; Chapter 5 is a paper written on the long-term effects of poultry manure on soil nutrient quality; and Chapter 6 gives general conclusions of this thesis research and recommendations for future studies. The list of references is included separately at the end of each chapter.

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CHAPTER 2: LITERATURE REVIEW

During recent years, the Midwestern States of the U.S.A. (i.e. Iowa, Illinois, and Kansas) have experienced a continuing increase in crop production (i.e. corn, soybeans, and wheat), livestock industry and poultry industry (USDA-NASS, 2005). In order to achieve high success in agricultural production, a large amount of fertilizer (both chemical and organic types) was applied to the field to sustain high yields. However, excessive use of fertilizer more than the crops need, definitely has resulted in contamination to groundwater in agricultural watersheds (Adam et al., 1994; Jaynes et al., 2001; Mitchell and Tu, 2005). Also, land-applied manure could potentially contaminate the groundwater due to NO_3-N leaching under excessive rainfall conditions. When absorbed into human body, NO_3-N can convert into nitrite (NO_2) which chemically interacts with oxy-hemoglobin of the blood system and could potentially cause the *Blue Baby disease* in children less than six months of age (U.S.-EPA, 1995). Therefore, reducing and controlling the nitrate leaching to groundwater have been extensively studied during the last few decades. This chapter reviews various studies on the effects of using poultry manure on water quality, crop production and soil properties after short-term and long-term applications.

Poultry manure as an alternate source of fertilizer for agricultural production

Poultry manure has a higher total solid content than most other manures. Dilution with water increases the potential for odor; therefore, handling the manure as a solid is usually preferred. Nearly all manure from animal feeding operations is applied to crop and pasture lands for agriculture practices such as, corn, soybeans, wheat, and so on. Practically, manure from animal feeding operations is applied directly into the field nearby for crop production. However, farmers have a tendency to over-apply manure rather than spreading over large areas at recommended rates because transportation costs are higher than the perceived fertilizer value of the manure (Ferguson et al., 2005). Manure not only provides high nutrient contents (N, P, and K) in comparison with chemical fertilizer, but also adds organic matters to the soil to improve soil structure, aeration, soil moisture-holding capacity, and water infiltration. Manure applied to field plots also risked the subsurface water and groundwater quality if handled improperly (Kanwar et al., 1988; de Vos et al., 2000). Therefore, the main concerns with land application of manure rely on whether it is safe for the environment and maintains the crop yield and crop quality (Power et al., 2001).

Effects of poultry manure application water quality

Subsurface drainage systems (SDS) lower the water table in wet months and make the poorly drained soils of the Midwest area become one of the most productive agricultural lands in the world. Figure 1 presented different types of SDS used in agricultural lands, but there has been much evolution in this area recently. As mentioned earlier, excessive use of fertilizer on manure will result in NO_3-N leaching into the tile drains and potentially contaminate both surface and groundwater (Dinnes, et al., 2002; Bergstrom and Kirchmann, 2004; and Herbst et al., 2005). Two main problems with the current SDS are the replacement of the old systems and management techniques to control the water quality from tile drains. Nolan et al. (1998) mapped areas in the U.S.A. having a high risk of nitrate contamination in shallow groundwater (Figure 2). The areas in red were well-drained soils, high N input and less woodland nearby the crop fields. Based on the risk of nitrate contamination map, the MSEA (Management Systems Evaluation Area) had characteristics of a high risk groundwater contamination area. Besides, some areas in both East and West Coastal areas of the U.S.A. were also in high alerted levels of nitrate contamination in groundwater. While the climatic factors (i.e. rainfall, temperature) can not be controlled, the current trends of SDS development are now objectively delaying or reducing volumes of drainage water by using both infield and downstream practices such as controlled drainage (Borin et al., 2001; Sands et al., 2003) and shallow drainage (Crumpton and Helmers, 2004). With a shallow drainage system, the water table is higher in winter and early spring, resulting in a larger anaerobic zone that promotes de-nitrification of excess nitrate-nitrogen below the tile drains (Spalding, et al., 2001; Nolan, et al., 2003; Owens and Bonta, 2004). Constructing wetlands to treat drainage water is one option (Tanner et al., 2005). Installing control valves into a drainage outlet can help manage the water table in the field. Another option is placing a biofilter in the tile line to increase the de-nitrification with a biological mechanism (Dao and Cavigelli, 2003). Patel et al. (2001) also suggested an upward movement of leached nitrate with sub-irrigation system and minimizing the nitrate concentration in the saturated zone to a safe limit within a short period of time. All these techniques will slow the water flow and increase crop yields, while decreasing the loss of nitrate and other pollutants into the groundwater. However, the common issues in drainage research are how to measure and sample the tile flow for nitrate concentration. Most of the studies applied periodic sampling such as one to three times per week during the crop season. Thus, most of information on nitrate leaching during the time after harvesting and before planting was missing and caused difficulty in calculating mass balance and N recovery by crop plants.

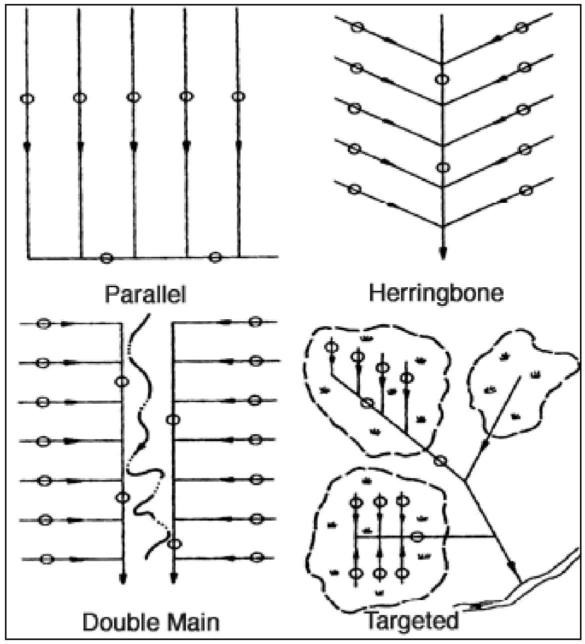

Figure 1. Different types of subsurface drainage used in agricultural land

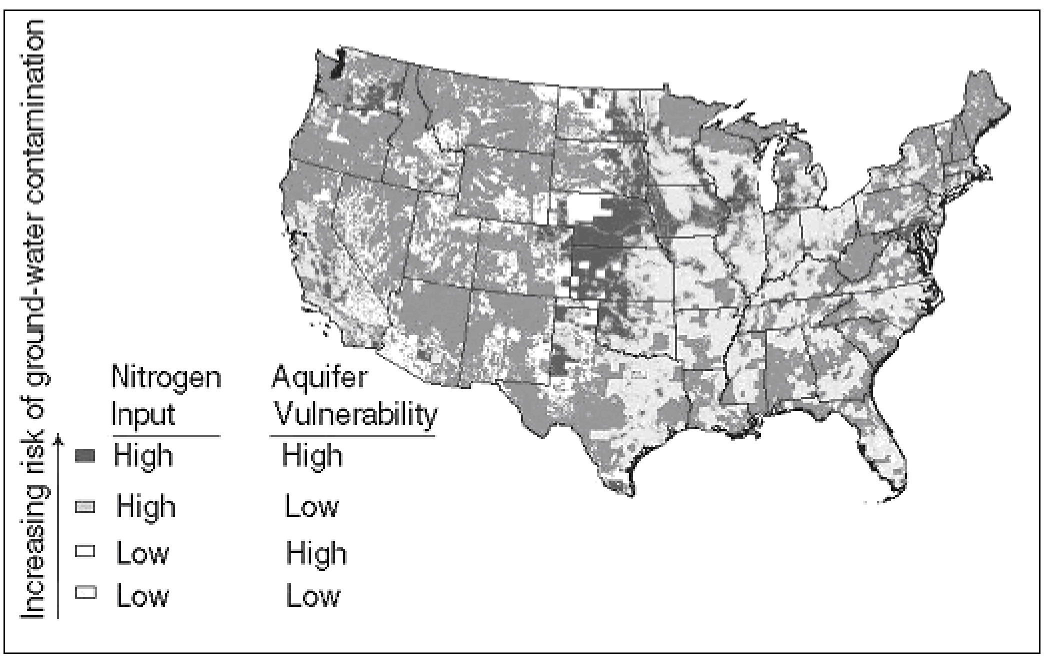

Figure 2. National map of high risk of nitrate contaminant in shallow groundwater (Nolan, et al. 1998)

Impacts of poultry manure utilization on crop production

Historically, crop rotation has been one alternative cropping system as opposed to monoculture. Corn after soybeans is one example of crop rotation in which soybeans fix nitrogen in the soil and credits it for corn growth in the following season. By diversifying different types of crop production systems, many benefits have been experienced in crop yield, crop quality, production cost for pesticide and fertilizer, and most importantly improvement of water quality (Karlen et al., 1998; Kanwar et al., 2005). Both short-term and long term studies have proved that intercropping and other alternative cropping systems reduced the NO_3-N and PO_4-P leaching losses into groundwater and residual NO_3-N and PO_4-P in soil profile. Pedersen and Lauer (2003) observed a 15% increase in corn yield after the first year applied crop rotation with soybeans in comparison with the previous five years of continuous corn planting. In other research, Varvel (2000) evaluated the long-term effects (16 years) of seven cropping systems with three N fertilizer rates. The results in Figure 3 (Varvel, 2000) confirmed that N fertilizer rates strongly affected continuous corn systems over years and suggested that different intercropping systems could achieve higher crop yields with proper management. There was not much variation in crop yield for corn after soybean rotation under three different N fertilizer rates. Thus, the intercropping system showed the possibility to reduce the risk of nitrate losses into groundwater.

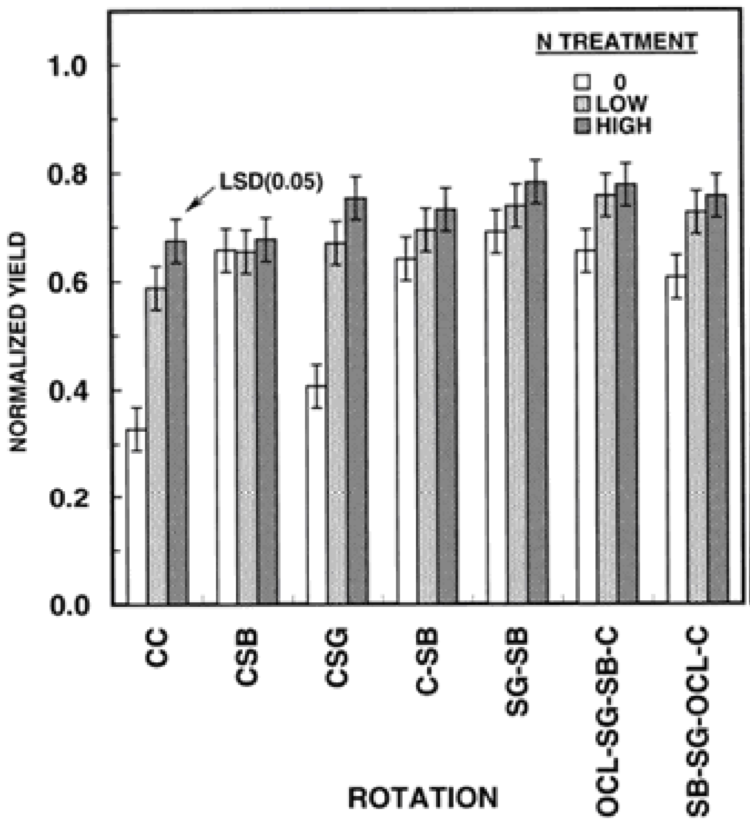

Figure 3: **Average normalized grain yields after 16 yr as affected by rotation and N treatment in a long-term cropping system study at Mead, NE**. (Varvel, 2000)

Rotation abbreviations: CC = continuous corn, CSB = continuous soybean, CSG = continuous sorghum, C-SB = corn-soybean, SG-SB = sorghum-soybean, OCL-SG-SB-C = oat + clover-sorghum-soybean-corn, SB-SG-OCL-C = soybean-sorghum-oat + clover-corn

In addition, Kanwar et al. (2005) investigated the role of traditional intercropping systems (corn after soybean) and the non-traditional intercropping systems (corn, soybean, oats, and alfalfa) on subsurface drain water quality. The non-traditional cropping system resulted in reducing NO_3-N losses by more than 100% in comparison with the traditional intercropping system during the six year study period (1993-1998). Naturally, the effects of diversity of crop rotation maximized the use of nutrients because legumes use N fixed from atmospheric N_2 and need little or no N fertilizer for their growth. Thus, the N fertilizer application rate for corn-soybean rotation was less than 100 kg-N/ha/year to achieve the similar crop yield in comparison with other systems. Besides, by reducing the N input, the residual of N in the top soil layer (0-30cm) was not significantly different between the application rate of (0 kg-N/ha) and that of (<100kg-N/ha) (Zhu and Fox, 2003). However, not many studies took into account the leaching of nitrate during the winter time or after snow melt. The variation of weather (rainfall rate, temperature) also influenced the biological transformation of nitrogen under these intercropping systems. Bakhsh et al. (2000) suggested having a better understanding of N-cycling processes taking place in the soil profile over the winter months. The authors also emphasized that the average over-winter changes in residual soil NO_3-N was greatest in corn plots previously fertilized with a single pre-plant application. In another study in Iowa to observe the effects of crop rotation, corn and soybeans were planted in the same plot with corn on one half of the field plot and soybeans on the other (Chinkuyu, 2000; Cheatham et al., 2002). The nitrogen fertilizer or poultry manure was applied to corn side only and the nitrate losses were 20% lower than those of corn after soybean rotation. In addition to the intercropping system, using crop cover (legume) to credit nitrogen for main crops (wheat, corn, etc.) and to minimize the winter effect did increase N use efficiency by improving the synchrony of N released from soil and plant N uptake. Cover crops will immobilize the soil-N released in the late fall and early spring. For example, an experiment with rye and oats as winter crop cover did reduce nitrate losses from 10kg-N/ha to 72 kg-N/ha during the time after harvest and before planting (Parkin et al., 2002). Kladivko et al. (2004) also found NO_3-N concentration in subsurface drainage can be reduced below 10 mg/L after long-time combination of reducing input N fertilizer, applying crop rotation, changing in tillage methods and growing winter crop after corn season.

Effects of poultry manure applications on soil quality

Poultry manure provides nutrient content of N, P, K as well as other minerals needed for plant use. In addition, poultry manure also provides many other benefits to improve soil properties and prevent soil erosion, especially after long time land application. Many studies have shown that using poultry manure over a long period of time would change the biological and chemical properties of the soil with the increase of soil organic matter (SOM) (Whalen et al., 2000; Yang et al., 2004; Moore and Edwards, 2005; Tejada et al., 2006; Varvel, 2006). Soil organic content supplied from poultry manure affects greatly the physical condition of the soil such as runoff, infiltration, water retention capacity, soil pH and so on (Hillel, D., 1998). Studies also proved that the application rates of poultry manure and types of poultry manure (broiler or litter) played the main role on the impacts of poultry manure on soil properties (Gilley et al., 2000). Moore and Edwards (2005) investigated the long-term effects of alum treated poultry litter and normal poultry litter manure on soil fertility and found that both treatments increased soil pH value from (5.1 – 5.3) in the beginning to (5.8 – 6.5) at the end of the experiment; thus, this decreased the exchangeable Al toxicity when compared to unfertilized controls. In this study, the authors also observed the decrease in soil pH linear with application rates of applied NH_4NO_3 fertilizer. Besides, with alum added to poultry manure, the losses via volatilization were also reduced significantly. Gao and Chang (1996) also found that after 18 annual applications of manure, the sand content in the 0 to 15-cm depth of soil in non-irrigated plots and in the 0 to 15 and 15 to 30-cm depths of soil in irrigated plots had decreased significantly. In addition, the changes in soil CEC, total organic carbon content and total nitrogen content in the 0 to 15 and 15 to 30-cm soil depth were reported to increase with the increasing rates of poultry manure. Soil fertility was also improved in the amended soil with poultry manure in term of increase in the available N, P for following crop season (Dean et al., 2000; Al-Kasi and Licht, 2004; DeLaune et al., 2004). The N and P content in crop residues in field plots receiving poultry manure were found higher than non-fertilized or chemical fertilized soils. Nitrogen (N) released through mineralization from broiler litter can supply the N requirements of crops, but litter may cause yield reductions and increased NO_3-N leaches losses if applied in excess of crop needs (Graetz et al., 1999; Flynn et al., 1993).

In summary, land application of poultry manure (broiler and litter) has shown to improve soil fertility and reduce soil acidity and toxicity (Al) in soil profile. However, in most of the studies, it is known that the effects of poultry manure changed with initial soil conditions, soil types, cropping systems and climatic regimes (Preusch et al., 2002; Bahl et al., 2002). A system approach is needed using a combination of cropping and tillage systems, N application rates, timing and application methods. Therefore, long-term studies are needed to critically examine the effects of poultry manure on water quality, soil erosion, soil quality and crop yields.

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CHAPTER 3

LONG-TERM EFFECTS OF POULTRY MANURE APPLICATIONS ON CROP YIELD UNDER A CORN AND SOYBEAN PRODUCTION SYSTEM

A paper to be submitted to *Transactions of ASABE* (American Society of Agricultural and Biological Engineers)

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ABSTRACT

Poultry manure has been shown to be a safe and valuable organic fertilizer source for agricultural production. A six year study was initiated in 1998 to study the effects of land application of poultry manure on corn and soybean production in Iowa. Four treatments include the application of poultry manure at two different nitrogen (N) rates (168kg-N/ha and 336 kg-N/ha), each with three replications, one application of chemical fertilizer NH_4-NO_3 (urea ammonium nitrate – UAN) at a rate of 168kg-N/ha with four replications, and a control treatment (0kg-N/ha). These experimental treatments were implemented on 0.4 ha field plots using a split plot design and requiring eleven field plots drained by a single subsurface tile drain system. Corn and soybeans were planted in field plots and rotated following the same procedure as that of the previous years. The results of this study showed that land application of poultry manure resulted in a significant increase in corn and soybean yields over the eight year period. However, applying poultry manure at higher rate (336 kg-N/ha) would cause either excessive N available for leaching or N available for corn in the latter season. The results also indicated that appropriate application rates of N from poultry manure not only yielded higher crop yields compared to other UAN treatment at similar rate but also resulted in higher crop N uptake capacity.

Abbreviations: SE- standard error, PM- poultry manure (168kg-N/ha), PM2 – poultry manure (336kg-N/ha), UAN- urea ammonium nitrate (168kg-N/ha)

INTRODUCTION

Since 2001, Iowa has become a leading state in the U.S.A. not only in corn and soybean production but also in the poultry and swine industry as well. According to USDA-NASS (2005), the grain yield of corn and soybeans in Iowa were at 54.9 million tons and 14.5 million tons, respectively. Besides, there was a significant increase in number of laying hens with approximately 44 million layers, producing 11.61 billion eggs (USDA-NASS, 2005). As a result of the stable development in poultry production, approximately 0.5 million tons of poultry manure has been released annually posing a potential threat to soil and water pollution. One of the common uses of poultry manure in Iowa is to utilize it as an organic N, P and K for crop production instead of chemical fertilizers. Basically, poultry manure has a higher total solid content than most other types of manures from animal species such as swine, beef, turkey, etc. and is considered as rich source of organic fertilizer for crop production. In the Midwestern States of the U.S.A. where 30% of the agricultural fields are drained using the subsurface drainage system, subsurface drain water is subject to contamination due to over application of manure in croplands (Tomer et al., 2003). The potential for contamination of ground and surface water through improper handling, disposal and land application of poultry manure is considerable because most poultry houses have a relatively small land base and transportation costs for poultry manure are high. Although poultry manure is one of the best organic fertilizers available, and is an extremely valuable resource, excessive land application rates can lead to nitrate and phosphorus leaching into groundwater, phosphorus (P) runoff losses into adjacent water bodies, and possibly cause elevated bacterial or pathogen levels in nearby lakes and rivers (Moore et al., 1995; Kanwar et al., 2005).

Typically, the input of nutrients from poultry manure has a great impact on crop yield, crop quality and environmental quality such as groundwater and surface and subsurface water quality. To approach the impacts of manure on nitrate losses via leaching, most of the studies focused on the effects on crop yield, crop quality and subsurface water quality of the manure application rates based on nitrogen (N-based), the timing (i.e. split, Fall application, Spring application) and methods (i.e. incorporated with soil by tillage or no-till) of application; and types of manure (composting, layer, littler, liquid or adding some chemical with manure) (Hegde, 1998; Jaynes et al., 2001; Dinnes et al., 2002; Tomer and Burkart, 2003; and Israel et al., 2005). In practice, based on the differences of the crop yield targets, crop productions and soil types, different application rates of manure were recommended and mostly on nitrogen base (N base, kg-N/ha). For example, Jaynes et al. (2001) studied the effects of three application rates of nitrate fertilizer on nitrate losses into groundwater towards corn-soybean field and classified the rates as low (57 – 67 kg-N/ha), medium (114 – 135 kg-N/ha) and high (172 – 202 kg-N/ha). Meanwhile, on the same corn-soybean rotation systems, Chinkuyu and Kanwar (2001) considered the low rate at 168 kg-N/ha and high rates at 336 kg-N/ha. However, in both cases, the results showed that the actual application rates were different from the desired rates because the variation of manure characteristics over years and the difficulties of manure analysis to measure the N-application rate (Dou et al., 2001). Besides, the miscalculation for the crop yield target also increased the application rate (Power et al., 2001). As a result, the optimum rate for reducing nitrate losses and maintaining the crop yield could not be achieved by controlling the application rate because even at the low rate (57-67 kg-N/ha), the nitrate losses via leaching was higher than 10 mg/L (MCL) of US-EPA. Thus, other approach should minimize the residual of nitrate in the soil profile after the crop season (Karlen et al., 1998).

The objectives of this study were: (1) to evaluate the long-term effects of two poultry manure application rates (168kg-N/ha and 336kg-N/ha) on crop yield and grain quality; (2) to develop the relationship between poultry manure application rates and nitrogen concentration in corn stalks; and (3) to compare the effects of poultry manure with that of chemical fertilizer (UAN) on crop yields and nitrogen concentrations in corn stalk. Such information would be useful in developing agricultural practices to improve N uptake efficiency by plants and minimize NO_3-N and PO_4-P leaching into groundwater.

MATERIAL AND METHODS

Field experiments were conducted from 1998 to 2005 at the Iowa State University's Agronomy and Agricultural Engineering Research Center near Ames, Iowa. The site is located on Nicollet loam soil formed in glacial till under the prairie vegetation with the organic matter content of about 4%. Nicollet soils are characterized as moderately permeable, somewhat poorly drained, produce surface runoff, have high available water capacity, and seasonal high water tables (Chinkuyu et al., 2002; Cheatham, 2003). Eleven field plots having the single subsurface tile drain in the middle of each field plot were used in this experiment. The size of each field plot varies from 0.19 ha to 0.42 ha. The map of the field plots is shown in Figure 1. One-half of each field plot (where corn was grown in previous year) was tilled every fall using a chisel plow, which ensured that about 30% of the crop residue was left on the surface. Corn (*Dekalb 580*) was planted on one half of each field plot and soybeans (*Kruger 2426*) were planted on the other half of the same plot followed by the same procedure of crop rotation from the previous years (1998-2005). Fertilizer was applied only on the corn side of each field plot. Poultry manure (PM) at two different rates (168kg-N/ha and 336kg-N/ha) and a chemical fertilizer (NH_4NO_3) at a rate of 168kg-N/ha – Urea Ammonium Nitrate (UAN) – were applied on the field plots by surface broadcast and incorporated into the soil by tilling the soil down to the depth of about 15 cm to reduce the loss of nitrogen via volatilization. A control plot was established with 0kg-N/ha for comparison purposes. Three poultry manure samples were collected and sent for analyzing the contents of N, P and K in order to determine the actual poultry manure application rates.

After harvesting, ten corn stalk samples were collected from each field plot at the height of 15 cm from the ground to determine the nitrogen content in corn plant.

Experimental Design and Data Analysis

Eleven treatments including two application rates of poultry manure (168kg-N/ha and 336kg-N/ha) with three replications, one application rate of UAN (168kg-N/ha) with four replications and a control treatment (0kg-N/ha) were laid out in a split plot design with unbalance replications. Analysis of variance (ANOVA) was performed to determine the significance of differences between the means using SAS software (SAS Institute Inc., 2001). The effects of fertilizer application rate, year, and the interactions between these variables on crop yield were evaluated. For evaluating the long-term effects, the comparisons were made between crop yields of odd and even years from 1998 to 2005. The increases in crop yields in each treatment over eight years were also tested to identify the benefits of land application of poultry manure on crop yields. The relationships between crop yield, tile flow and corn stalk quality over eight years were determined using correlation procedure of SAS. The statistical analysis was conducted separately for corn and soybean yield data. In all of the statistical analysis, a significant level $\alpha = 0.05$ was used to evaluate the significant difference among all hypothetical testing.

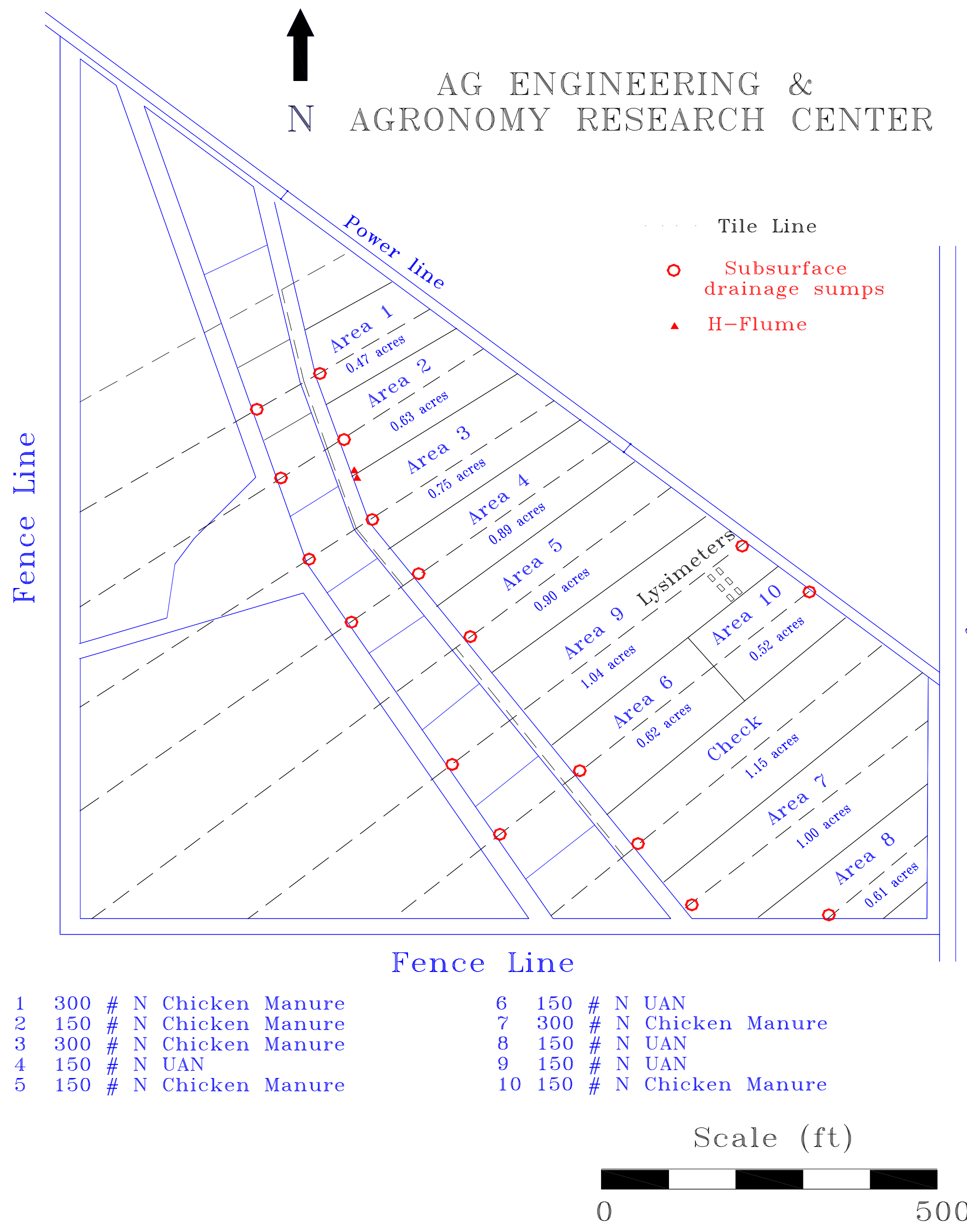

Figure 1. Experimental lay out of field plots

RESULTS AND DISCUSSION

Poultry manure application rates

Table 1 gives data on poultry manure applied on field plots during an eight year period (1998-2005) and the averages of actual poultry manure application rates are given in Table 2. The determination of amount of poultry manure applied in each year was based on the assumption that 5% N lost during the application process and 75% N was available during the year for plant uptake (Cheatham, 2003). No credit of residual N, K and P was taken from the soybean year for corn in the following year. The results of the eight year study showed that the actual manure application rates overall were higher than the target application rates of the experiment. The intended application rates of poultry manure were 168kg-N/ha for the low rate and 336kg-N/ha for the high rate. However, the average actual rates over eight years were 202 kg-N/ha and 375 kg-N/ha for the low and high rates, respectively. These differences were due to the fluctuation in poultry manure characteristics over years. Basically, animal manure is heterogeneous and nutrient contents of manure samples vary (Rieck-Hinz et al., 1996). Such changes can affect crop yield if poultry manure is applied on a long-term basis for agricultural production (Dou et al., 2001).

Rainfall and tile flow

The hydraulic characteristics of the experimental site and the volume of subsurface drainage water from the field plots are shown in Figures 2a,b. The average tile flow for each treatment is presented in Tables 3a,b. These results show that there was a significant difference in the volume of tile flow among treatments ($p < 0.0001$) over the eight year period. For each treatment, the variation in tile flow over the years was also significantly different ($p<0.001$). However, there was not a strong relationship between rainfall and tile flow volumes for four treatments (p=0.423). In addition, the PM treatment (168kg-N/ha) had the lowest tile flow (with an average tile flow of 6.8 cm and the standard error of 2.1 cm) in comparison with the other treatments over the eight year period. The control treatment which received neither chemical fertilizer nor poultry manure fertilizer had the highest tile flow in comparison with other treatments (with an average tile flow of 17.01 cm and standard error of 1.6 cm).

Crop Yields

The grain yields of corn and soybeans are presented in Tables 4a, and 4b, respectively. Overall, the results of this show that there is a significant difference between corn yields as affected by poultry fertilizer application rates. The PM2 (336 kg-N/ha) treatment gave the highest average corn yield of 11,115 kg/ha with the standard error of 349 kg/ha. The response of crop yield to the various treatments over the eight year period was ranked as PM2>PM>UAN>None (Figure 3). These results also showed that there was no significant difference in soybean yields between PM (168 kg-N/ha) and PM2 (336 kg-N/ha) treatments (Figure 4). The average soybean yields from PM and PM2 treatment were higher in comparison with the UAN and control treatment (0kg-N/ha). A significant increase in crop yields (corn and soybean) of PM and PM2 treatments over UAN treatment was observed although high fluctuations in crop yield was apparent due to the changes in rainfall and fertilizer application rates over years (Table 5).

In this experimental study, corn and soybean were planted on the same plot to investigate the crop rotation effect of corn-soybean system over the eight year period. Corn was planted and received poultry manure or UAN on its half side of the field plot. Soybeans were planted and received no fertilizer (poultry manure or UAN) on its half side. The position of corn and soybean side was rotated yearly during the experimental period (1998-2005). Therefore, the effect of crop rotation in each field plot on crop yield was hypothesized to be a significant difference over eight years. However, the difference of crop yield for all plots in odd (1999, 2001, 2003, 2005) and even years (1998, 2000, 2002 and 2004 was not significant (p=0.143) even though the average of crop yield in even years was 138kg/ha higher than that of odd years. Besides, the average crop yield in 2004-2005 was higher than that of previous six year average (1998-2003) by 220 kg/ha for corn yield and 281 kg/ha for soybean yield. Therefore, these results may suggest that long-term land application of poultry manure for corn-soybean rotation may benefit both corn and soybean yields.

Table 1. Characteristics of Poultry Manure Applied to Field Plots

Year	1998	1999	2000	2001	2002	2003	2004	2005
Total Kjedhal N, % N	1.49	3.04	2.69	2.16	1.41	2.03	2.36	2.04
Ammonia (NH3), %N	1.00	4.37	3.94	2.72	2.24	1.60	1.59	0.20
Total Phosphorus, %P	1.43	2.29	2.41	2.62	1.20	1.81	2.08	1.66
Potassium, %K	1.11	0.74	0.72	0.85	0.57	1.71	1.13	0.82
Moisture Content, %H2O	48.12	45.03	32.60	56.97	53.70	76.25	69.93	27.70

Table 2. Average Manure Application Rates for Field Plots (1998-2005)

	168 kg N/ha poultry manure				336 kg N/ha poultry manure			
	Average manure application rate, (kg/ha)	Average application rate, (kg/ha)			Average manure application rate, (kg/ha)	Average application rate, (kg/ha)		
Year		**N**	**P**	**K**		**N**	**P**	**K**
1998	10674	159	106	152	24190	364	228	303
1999	9575	291	418	220	14774	440	622	275
2000	3213	86	127	77	8741	326	328	196
2001	8998	195	244	115	14957	324	407	192
2002	7982	249	179	95	14295	377	321	171
2003	11318	229	182	205	18231	369	291	331
2004	7739	230	202	110	15446	458	404	220
2005	6960	178	146	72	13377	343	279	138
Average	**8307**	**202**	**200**	**131**	**15501**	**375**	**360**	**228**

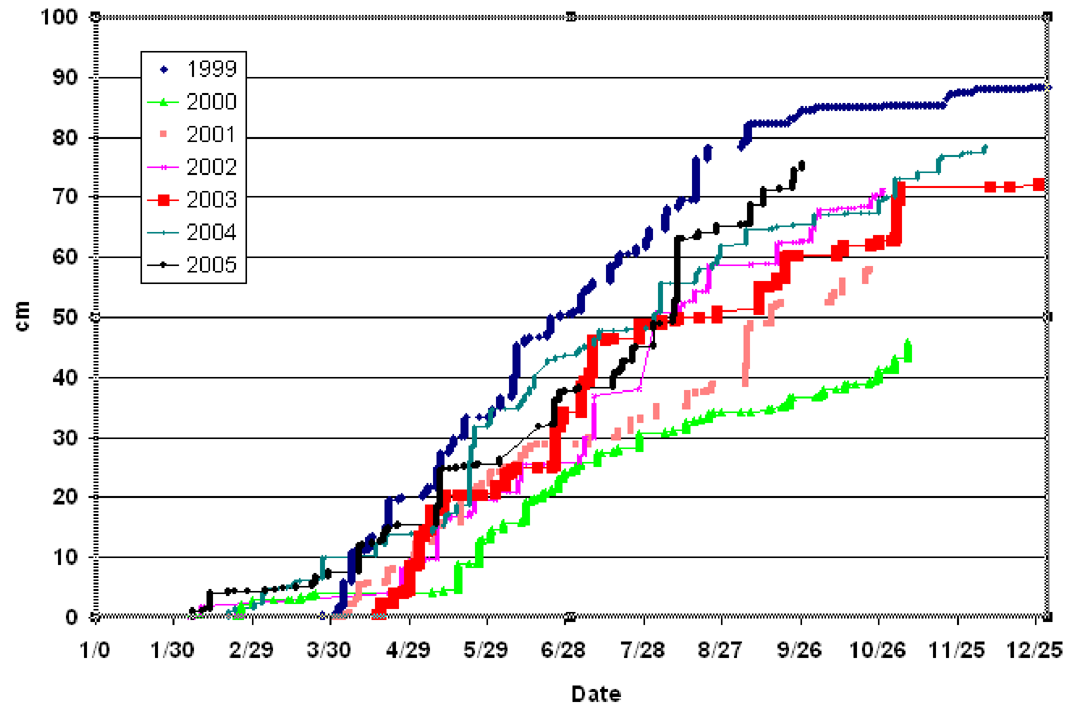

Figure 2a. Rainfall data from field five over eight years (1998-2005)

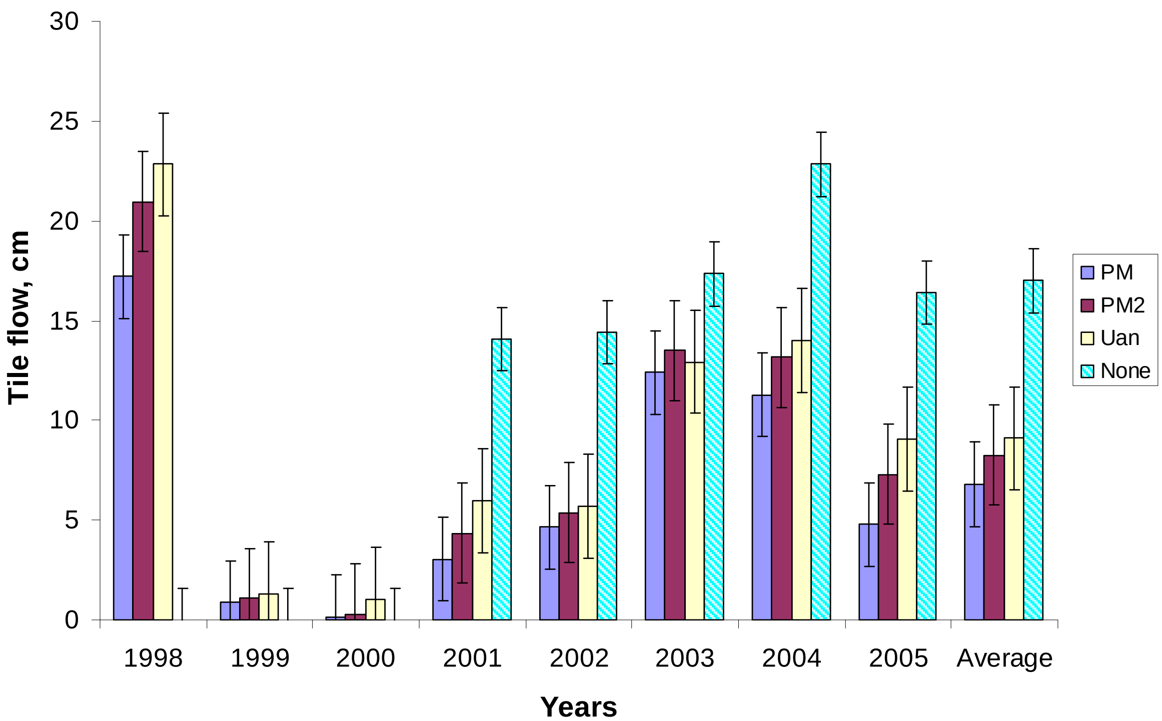

Figure 2b. Average subsurface drainage flow rates from field plots (1998-2005)

Table 3a. Accumulative rainfall and tile flow rates averaged by treatment (1998-2005)

Year	1998		1999		2000		2001		2002		2003		2004		2005		Average	
Treatment	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)
PM	33.73	17.22	45.19	0.86	16.87	0.17	52.45	3.03	46.66	4.64	42.55	12.4	43.38	11.28	55.60	4.78	42.05	6.8
PM2	33.73	20.97	45.19	1.10	16.87	0.30	52.45	4.35	46.66	5.38	42.55	13.51	43.38	13.17	55.60	7.29	42.05	8.2
UAN	33.73	22.83	45.19	1.29	16.87	1.02	52.45	5.95	46.66	5.72	42.55	12.94	43.38	14.01	55.60	9.07	42.05	9.10
None	33.73	N/A	45.19	N/A	16.87	N/A	52.45	14.06	46.66	14.41	42.55	17.35	43.38	22.83	55.60	16.40	42.05	17.01

Note: RF: total rainfall during the growing season from March to October
TF: total tile flow from subsurface drainage of field plots averaged by treatment

Table 3b. Average tile flow from field plots (1998-2005)

Treatment	n	Tile Flow * (cm)	SE
PM (168 kg-N/ha)	24	6.80	0.52
PM2 (336 kg-N/ha)	24	8.26	0.52
UAN (168 kg-N/ha)	16	9.10	0.63
None (0 kg-N/ha)	5	17.01	0.89

* Average of tile flow over 8 years (1998-2005)

Table 4a. Corn yield average under four treatments from 1998 to 2005

	Corn Yield, kg/ha									
Treatment	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average***	**SE**
PM (168kg-N/ha)	10,007	11,098	10,645	9,768	11,311	10,082	10,142	10,388	10,430[a]	154
PM2 (336 kg-N/ha)	9,678	11,265	10,669	10,017	12,192	10,854	11,937	12,311	11,115[b]	154
UAN (168kg-N/ha)	8,911	9,671	9,453	8,658	10,374	9,583	11,161	11,771	9,948[c]	133
None (0 kg-N/ha)	4,326	5,783	6,971	6,629	4,894	6,759	6,423	6,263	6,006[d]	267

* The values in the same column followed by the same letter are not significantly different at p=0.05

Table 4b. Soybean yield average under four treatments from 1998 to 2005

	Soybean Yield, kg/ha									
Treatment	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average***	**SE**
PM (168kg-N/ha)	3,921	3,885	3,317	3,132	2,415	3,125	3,794	3,845	3,429[a]	84
PM2 (336 kg-N/ha)	4,254	3,930	3,333	3,305	2,144	3,031	3,986	4,209	3,524[a]	84
UAN (168kg-N/ha)	4,036	3,610	2,746	2,764	1,650	2,825	3,524	2,862	3,002[b]	73
None (0 kg-N/ha)	3,527	3,486	2,306	2,498	868	2,603	2,737	2,271	2,537[c]	146

* The values in the same column followed by the same letter are not significantly different at p=0.05

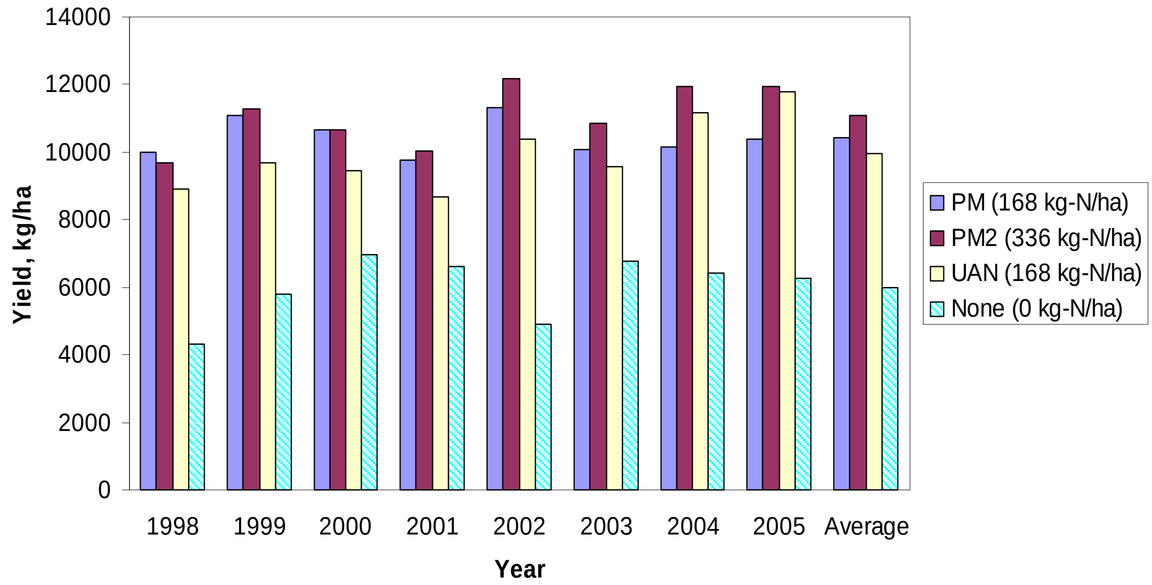

Figure 3. Corn yield for different types and application rates over eight years (1998-2005)

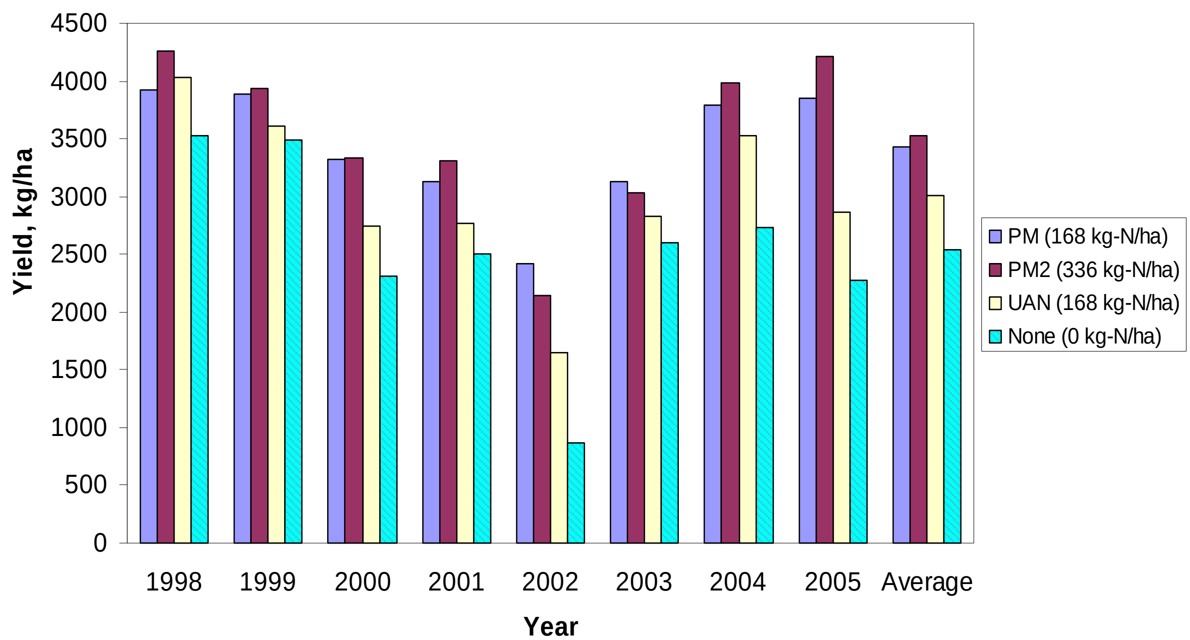

Figure 4. Soybean yield for different manure and UAN application rates over eight years (1998-2005)

Table 5. Average increase of crop yield in poultry manure treatments in comparison with that of UAN fertilizer treatment (1998-2005)

Treatment	Corn yield (kg/ha)	Pr < |t|	Soybean yield (kg/ha)	Pr < |t|
PM (168kg-N/ha)	482	0.143	427	0.101
PM2 (336kg-N/ha)	1168	0.020	522	0.080

Nitrogen in Corn Stalks

The information on N concentration in corn stalks has been proposed as the basis for evaluating the N status of corn as well as soil (Binford et al., 1992). Based on corn stalk information, the grower might have better control in developing future fertilizer-N management practices, thereby improving profitability and reducing environmental degradation (Wilhelm et al., 2005). The data on nitrogen concentration in the corn stalks collected from field plots is presented in Figure 5. Also data on average N concentration in corn stalks and corn yield for each treatment is presented in Table 6. The data in Figure 5 and Table 6 show a large variation in N concentrations in the corn from year to year and from treatment to treatment. When averages were taken across the years (1998-2005), the N concentration in corn stalks for all treatments (PM2, PM, UAN and none) were 1121, 3463, 1395 and 31 ppm N, respectively. The treatment PM2 gives the highest N uptake in corn stalks and no significant difference was found in N uptake in corn stalks between PM and UAN treatments (p=0.862). These results were found to agree with those of Cheatham's experiment (Cheatham, 2003) which used the same experimental site and design. Besides, Steven et al. (2005) also studied the effects of long-term N application rates on the ability of crop N uptake and also found that the crop uptake labeled N increased with the increase in fertilizer application rates (Stevens, W. B. *et al.*, 2005). According to the classification and assessment of Varvel et al. (1997) for the stalk nitrate test and its association with crop yield's threshold, the results proved that PM2 treatment gave excessive levels of N available to the crop (eight year average NO_3-N concentration in corn stalks was > 3500 mg/kg) and the levels of N in corn stalks of PM and UAN treatments were in moderate range of which the fertilizer application rate was suitable or in favor of crop yield and the N available did not limit the crop yield (Binford et al., 1992). Therefore, the PM treatment showed a better effect on crop yield and reduced the potential of environmental degradation due to long term land application of poultry manure.

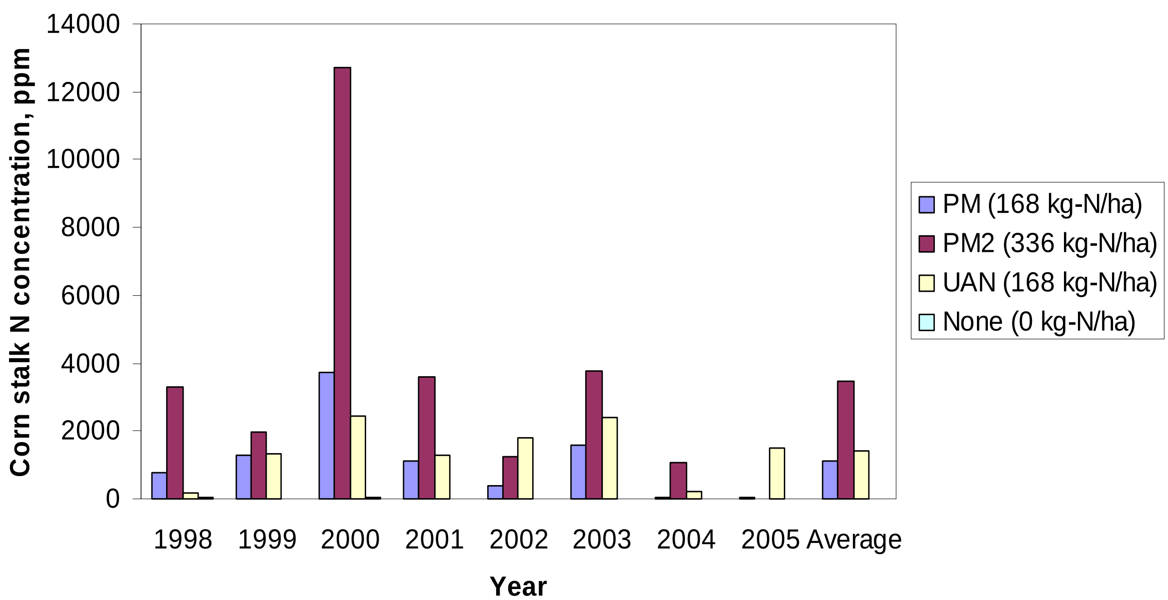

Figure 5 Corn stalk N from field plots over eight years (1998-2005)

Table 6. Average of corn yield and nitrogen in corn stalk from field plot (1998-2005)

Treatment	Corn yield* (kg/ha)	Pr > F	Corn Stalk N (ppm)	Pr > F
PM (168kg-N/ha)	10,430	<0.0001	1121	<0.0001
PM2 (336 kg-N/ha)	11,115	<0.0001	3463	<0.0001
UAN (168kg-N/ha)	9,948	<0.0001	1395	<0.0001
None (0 kg-N/ha)	6,006	<0.0001	31	0.9125

CONCLUSIONS

A long-term study (1998-2005) was conducted to evaluate the effects of land application of poultry manure on crop yield under a corn-soybean rotation production system in Iowa. The results of this study show that poultry manure helped to increase the crop yield by 5% for PM treatment and 14% for PM2 treatment in comparison with UAN treatment. On average, at both rates (168kg-N/ha and 336kg-N/ha), the poultry manure treatment yielded a higher crop yield in comparison with the UAN. However, the high application rate (336kg-N/ha) of poultry manure resulted in excessive N uptake by corn through the stalk and caused a potential environmental degradation problem for soil. Water quality for crop residue is normally mixed into the soil after harvesting. Therefore, the lower rate of poultry manure application (168kg-N/ha) is recommended as a poultry manure management practice of land application in a corn-soybean production system in Iowa.

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CHAPTER 4

LONG-TERM EFFECTS OF POULTRY MANURE APPLICATIONS ON SUBSURFACE WATER QUALITY UNDER A CORN AND SOYBEAN PRODUCTION SYSTEM

A paper to be submitted to *Transactions of ASABE* (American Society of Agricultural and Biological Engineers)

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ABSTRACT

Nutrient losses from artificially drained croplands via leaching are influenced by many factors such as weather, soils, fertilizer application rates, and agricultural practices. A long-term field study was conducted to evaluate the impacts of poultry manure application on nutrient losses through subsurface drainage systems under a corn and soybean rotation system in Iowa. Nine field plots about 0.4 ha in size and each drained by a single subsurface tile drain were used in this experiment. Three treatments included two application rates of poultry manure (to give 168 kg-N/ha (PM) and 336 kg-N/ha (PM2)), one application rate of UAN (urea ammonium nitrate) (to give 168 kg-N/ha) and a control treatment (with 0 kg-N/ha). These treatments were applied using split plot design with unbalance replications. Effluent from the tile drain was collected at the end of each plot by using a sump and analyzed for NO_3-N and PO_4-P concentrations. Tile flow from each field plot and rainfall data were recorded during the experiment period (from April to October). The results of this study showed that non-fertilized (control treatment) and chemical fertilized field plots (with UAN) yielded higher tile flow than those receiving manure applications. After eight years of poultry manure and UAN application, the average NO_3-N losses with tile drain water in PM and PM2 treatment were 13.65 kg/ha and 18.67 kg/ha, respectively. PO_4-P leaching loss in

tile drain water under PM treatment was also found to be lower than PM2 and UAN treatment. These results clearly indicated that long-term land application of poultry manure at lower rate (to give 168 kg-N/ha) resulted in significantly lower NO_3-N and PO_4-P leaching losses with subsurface drain water.

Abbreviations: SE- standard error, PM- poultry manure (168kg-N/ha), PM2 – poultry manure (336kg-N/ha), UAN- urea ammonium nitrate (168kg-N/ha)

INTRODUCTION

Poultry manure is considered a rich organic fertilizer source for crop production. In Midwestern States of the U.S.A. where 30% of the agricultural cropland has been drained with the subsurface drainage systems, subsurface drainage water has become a source of water pollution concern due to manure applications on cropland (Tomer et al., 2003; Baker et al., 2004). Therefore, the current subsurface drainage systems in Iowa are also draining NO_3-N and PO_4-P from animal manure treated field plots that eventually resulted in contaminating the surface water supplies (Baker et al., 1975; Lawlor et al., 2004). Higher N losses from poultry manure treated fields attributed to de-nitrification and high N uptake by plants (Chinkuyu and Kanwar, 2001). Several studies have been conducted on the role of different cropping systems on water quality. These studies showed that there is a strong correlation between manure application rates and NO_3-N and PO_4-P concentration in tile drain water, and the total nutrient losses with subsurface drainage water were associated with the amount of manure applied on the surface (Kanwar et al., 1988; Adams et al., 1994; Jaynes et al., 2001; Bakhsh et al., 2002 and Kanwar et al., 2005). Nitrate concentrations in the shallow zone of the aquifer were higher (Spalding et al., 2001). The prediction of optimum manure application rates, however, is complicated by the mineralization of organic N that accumulates with repeated manure applications over many years (Change and Janzen, 1996). Stoddard et al. (2005) found that applying both fertilizer N and manure significantly increased NO_3–N concentrations in the leachate compared with the control treatment. In this study, the NO_3–N concentration in the leachate at the application rate of 168 kg-N/ha in amended soils with manure was reported to exceed 10 mg/L and higher than soils receiving chemical N fertilizer. The authors concluded that long-term manure use can have substantial positive impacts, though delayed, on NO_3–N leaching potential due to continued mineralization of N from accumulated manure-derived organic matter. Another long-term study by Kingery et al., (1994) found that long-term land application of broiler litter resulted in altering the soil chemical conditions and created a potential for adverse environmental impacts in the Sand Mountain region of Alabama. Owens and Shipitalo (2006) found the phosphorus losses with subsurface drainage water were less than 0.15 kg/ha under long-term fertilized pasture in Ohio and the environmental impacts of phosphorus on drainage water quality would not be a great concern.

However, the long-term effects of manure on subsurface water quality depend on soil characteristics, cropping system, management practices and changes in weather condition (i.e. rainfall rates, seasonal effects) (Weed and Kanwar, 1996; Zhao et al., 2001; Moog and Whiting, 2002; Kladivko et al., 2004). For the crop rotation system in which corn and soybean were planted in the same field plot, not much information about the long-term impacts of poultry manure on subsurface water quality was reported until the present study was initiated. Therefore, a field study was conducted to investigate the long-term effects of poultry manure on water quality under a corn-soybean rotation system. The overall objectives of this research were (1) to determine subsurface drain flows and NO_3-N and PO_4-

P leaching with drain flow under poultry manure and commercial UAN fertilizer application methods and (2) to evaluate the long term effects of land application of poultry manure on water quality.

MATERIALS AND METHODS

Field experiments were conducted from 1998 to 2005 at the Iowa State University's Agronomy and Agricultural Engineering Research Center near Ames, Iowa. The site is located on Nicollet loam soil formed in glacial till under the prairie vegetation with the organic matter content of about 4% and a maximum slope of 3%. Nicollet soils are characterized as moderately permeable, somewhat poorly drained, produce surface runoff; have high available water holding capacity, and seasonal high water tables (Chinkuyu et al., 2002; Cheatham, 2003). Nine field plots drained by a single subsurface tile drain in the middle of each field plot were used in this experiment. These tile drains were intercepted at the end of each field plot and a V-notch and sump installed for water quality sampling. The size of each field plot varied from 0.19 ha to 0.42 ha. The map of the field plots is shown in Figure 1. One-half of each field plot (where corn was grown in the previous year) was tilled every fall using a chisel plow, which ensured that about 30% of the crop residue was left on the surface. Corn (*Dekalb 580*) was planted on one half of each field plot and soybeans (*Kruger 2426*) on the other half. Either poultry manure (PM) or UAN fertilizer was applied on the corn side in each field plot. PM was applied at two different rates (168kg-N/ha and 336kg-N/ha) and UAN fertilizer (NH_4NO_3) was applied at a rate of 168kg-N/ha using surface broadcast methods, and then incorporated into the soil within 48 hours by tilling the soil down to the depth of about 15 cm to reduce the loss of nitrogen via volatilization. A control plot, receiving 0 kg-N/ha, was also established. Three poultry manure samples were collected and sent to the lab for analyzing the content of N, P and K in manure composition to determine the actual N application.

The monitoring devices in the sum helped to measure the volume of tile drain flow from tile drain and collect the subsurface drain water samples on a weekly basis from March to August every year (1998-2005). Two sets of water samples from each plot were collected in 125mL plastic bottles. One bottle was acidified with sulfuric acid for NO_3-N analysis and the other bottle was analyzed for PO_4-P.

Experimental Design and Data Analysis

Four treatments including two application rates of poultry manure (168kg-N/ha and 336kg-N/ha) with three replications for each rate, one application rate of UAN (168kg-N/ha) with two replications and a control (0kg-N/ha) were laid out on eleven experimental field plots in a split plot design with unbalance replications (Figure 1). Analysis of variance (ANOVA) was performed to determine the significance of differences between the means of NO_3-N and PO_4-P concentration and losses using proc mixed in SAS program (SAS Institute Inc., 2001). The effects of fertilizer application rates, type of fertilizer (PM vs. UAN), timing, crop rotations (nested in year) and the interaction between these variables on NO_3-N and PO_4-P concentration and losses with subsurface drain flow were investigated. Long-term impacts of poultry manure application on water quality were evaluated by comparison of average NO_3-N and PO_4-P losses with subsurface drain water for the eight year study (1998-2005). A comparison between nutrient losses (NO_3-N and PO_4-P) in odd and even years from 1998 to 2005 was made to evaluate the variation in rainfall. In all of the statistical analyses, a significant level $\alpha = 0.05$ was used to evaluate the significant difference between the means.

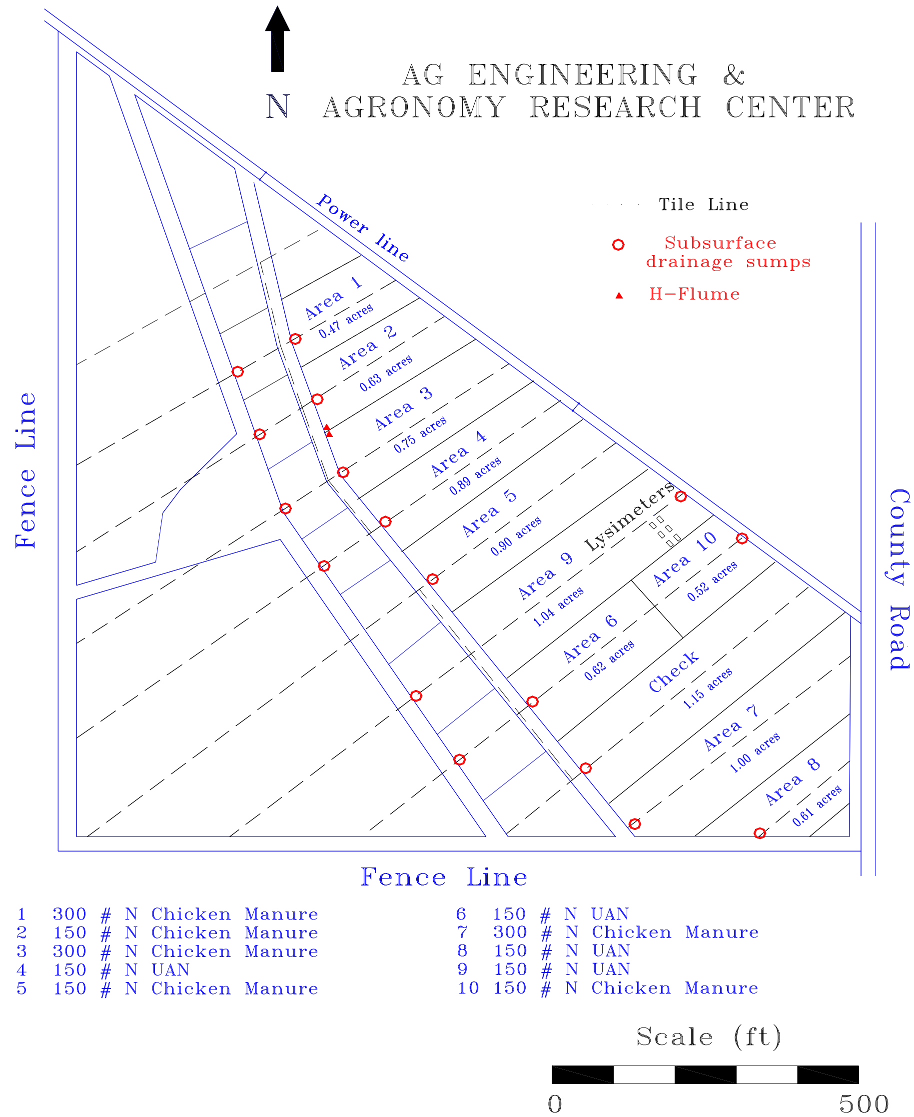

Figure 1. Experimental layout of 11 field plots for water quality study

RESULTS AND DISCUSSION

Rainfall and tile flow

The hydrologic characteristics of the experimental site and the volume of drainage water from tile drains of the field plot are shown in Figures 2a and 2b. The eight year average tile flow for each treatment is presented in Table 1a. The data in Table 1a shows that there was a significant difference in tile flow volume among the treatments ($p < 0.0001$). For each treatment, the variation in tile flow over the years was also significantly different ($p<0.001$). However, there was not a strong relationship between rainfall rates and tile flows of four treatments for all years under the experimental condition ($p=0.423$). Also, the data in Table 1b shows that the PM treatment (168kg-N/ha) had the lowest tile flow (average tile flow of 6.8 cm with standard error of 2.1 cm) in comparison with the other treatments. The control treatment (0 kg-N/ha) resulted in the highest tile flow (average tile flow of 17.01 cm with standard error of 1.6 cm) (Table 1b). This could be due to lowest evapo-transpiration rates in the control treatment.

Nitrate concentration and losses with subsurface tile flow

The data on NO3-N concentration in tile flow is shown in Figure 3. The annual NO3-N losses with drain water for various treatments are shown in Figure 4. Also, Table 2 gives the average NO3-N concentrations and losses with drain water for eight years as a function of poultry manure and UAN application rates. In general, the results show that there was a large variation in nitrate concentrations and losses over the first six years (1998-2003) of this study; however, the fluctuation in nitrate concentration and losses appear to decrease during the last two years (2004-2005) of the study. Overall, the average NO3-N concentrations in tile drain water for all treatments (PM, PM2, UAN and None) were 17.37, 25.3, 18.8, and 10.81 mg/L, respectively and the corresponding average nitrate losses were 13.65, 18.57, 14.38, and 12.73 kg-N/ha. These results show that PM2 treatment resulted in the highest NO3-N concentration and losses with subsurface drain water in comparison with other treatments. The PM treatment resulted in significantly lower NO3-N losses in comparison with the PM2 and UAN ($p < 0.0001$). These results are in agreement with the findings of the previous study (1998-2003) from this site (Cheatham, 2003). In addition, a comparison between the average nitrate losses from the first six years (1998-2003) and the last two years (2004-2005) years of this study period showed that the NO3-N losses for the first six year period were about 2.97 kg-N/ha higher in comparison to the average NO3-N losses for the last two years (2004-2005). This shows that there is a likelihood that NO3-N losses over longer period may decrease from field plots receiving continuous application of poultry manure for corn-soybean production. This also necessitates the need for conducting water quality data on long-term basis.

Phosphorus concentration and losses in tile drain

Unlike NO_3-N ion which is highly soluble in water, phosphorus has a tendency to get adsorbed with soil particles and the main pathway of PO_4-P losses to water bodies is due to surface runoff. Flow weighted phosphorus concentration and losses are presented in Figure 5 and Figure 6. Also, a summary on tile flows, phosphorus concentration and losses with tile drains water over the eight year period of the study are presented in Table 3. These results showed that a significant difference was observed in phosphorus losses in tile drain water among the treatments. The PM treatment gave PO_4-P concentration and losses of 0.0076 mg/L and 0.0073 kg/ha, respectively which were lower than those of PM2 and UAN treatments (0.0156; 0.0088 mg/L and 0.0116; 0.0072 kg/ha, respectively). However, the difference between PM and UAN treatment on PO_4-P concentration and losses was not significant (p=0.544). The PM2 treatment resulted in PO_4-P losses nearly two times higher than that of PM treatment. In addition, the loss of phosphorus from this experiment was much lower in comparison with that of NO_3-N losses with tile drain water (Table 4). These results also show that lower PO_4-P losses with tile drain water may be due to accumulation of PO_4-P in the soil profile.

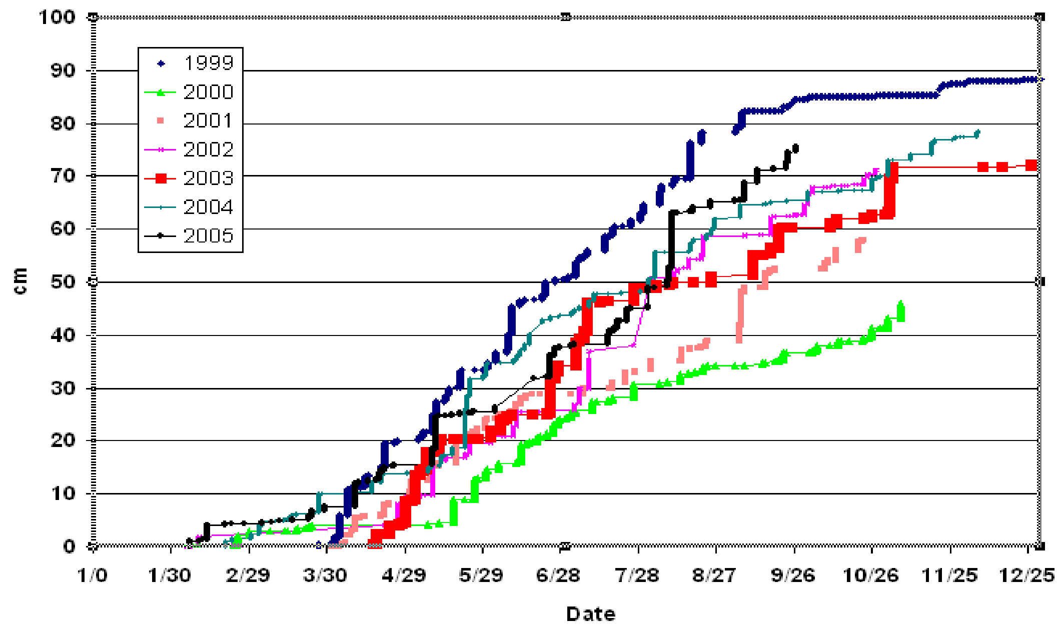

Figure 2a. Accumulative rainfall data from field five for eight years (1998-2005)

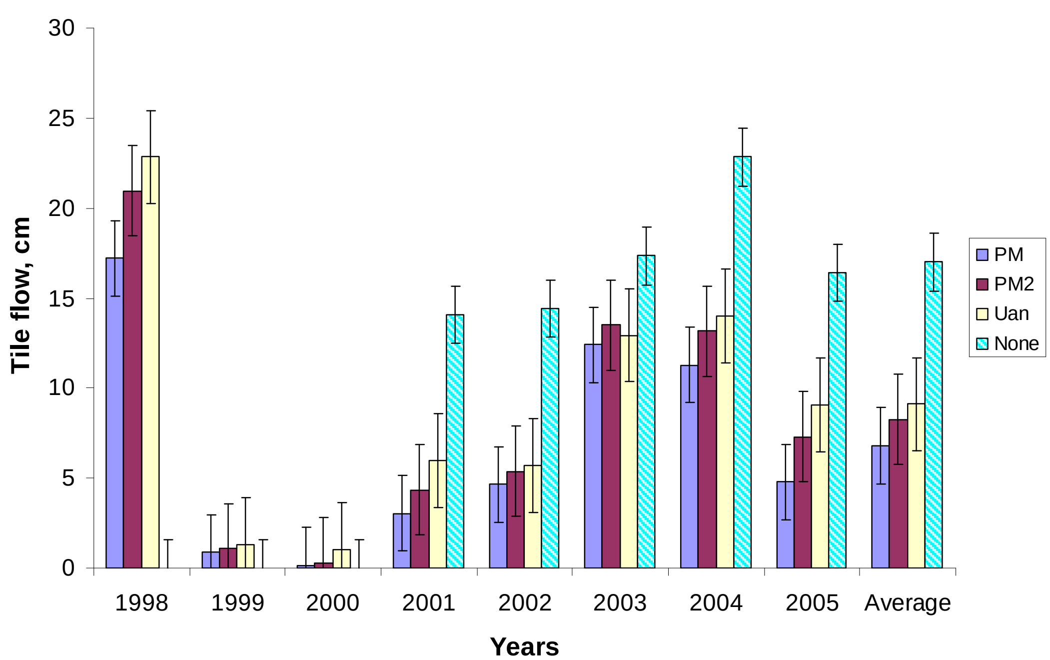

Figure 2b. Variability in subsurface drain flow for eight years (1998-2005) of four treatments

Table 1a. Accumulative rainfall and tile flow rates averaged by treatments (1998-2005)

Year	1998		1999		2000		2001		2002		2003		2004		2005		Average	
Treatment	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)	RF (cm)	TF (cm)
PM	33.7	17.2	45.2	0.9	16.9	0.2	52.5	3.0	46.7	4.6	42.6	12.4	43.4	11.3	55.6	4.8	42.1	6.8
PM2	33.7	20.9	45.2	1.1	16.9	0.3	52.5	4.4	46.7	5.4	42.6	13.5	43.4	13.2	55.6	7.3	42.1	8.2
UAN	33.7	22.8	45.2	1.3	16.9	1.0	52.5	5.9	46.7	5.7	42.6	12.9	43.4	14.0	55.6	9.1	42.1	9.1
None	33.7	N/A	45.2	N/A	16.9	N/A	52.5	14.1	46.7	14.4	42.6	17.4	43.4	22.8	55.6	16.4	42.1	17.0

Note: RF: total rainfall during the growing season from March to October
TF: total tile flow from subsurface drainage of field plots averaged by treatment

Table 1b. Average tile flow from field plots (1998-2005)

Treatment	n	Tile Flow * (cm)	SE
PM (168 kg-N/ha)	24	6.8[a]	2.1
PM2 (336 kg-N/ha)	24	8.3[ab]	2.5
UAN (168 kg-N/ha)	16	9.1[bc]	2.6
None (0 kg-N/ha)	5	17.0[d]	1.6

* Average of tile flow over eight years (1998-2005)

Table 2. Average of tile flow and nitrate load in tile drain over eight years (1998-2005)

Treatments	Tile flow (cm)	NO3-N concentration (mg/L)*	NO3-N loss (kg/ha)*
PM (168 kg-N/ha)	6.80	17.37[a]	13.65[a]
PM2 (336 kg-N/ha)	8.26	25.30[b]	18.57[b]
UAN (168 kg-N/ha)	9.10	18.80[c]	14.38[c]
None (0 kg-N/ha)	17.01	10.81[d]	12.73[d]

* The values in the same column followed by the same letters are not significantly different at significant level ($\alpha = 0.05$).

Table 3. Average of tile flow and phosphate load from tile drain under treatments over eight years (1998-2005)

Treatments	Tile flow (cm)	PO_4-P concentration (mg/l)*	PO_4-P loss (kg/ha)*
PM (168 kg-N/ha)	6.80	0.0076[a]	0.0073[a]
PM2 (336 kg-N/ha)	8.26	0.0156[b]	0.0116[b]
UAN (168 kg-N/ha)	9.10	0.0088[a]	0.0072[a]
None (0 kg-N/ha)	17.01	0.0079[c]	0.0107[c]

* The values in the same column followed by the same letters are not significantly different at significant level ($\alpha = 0.05$).

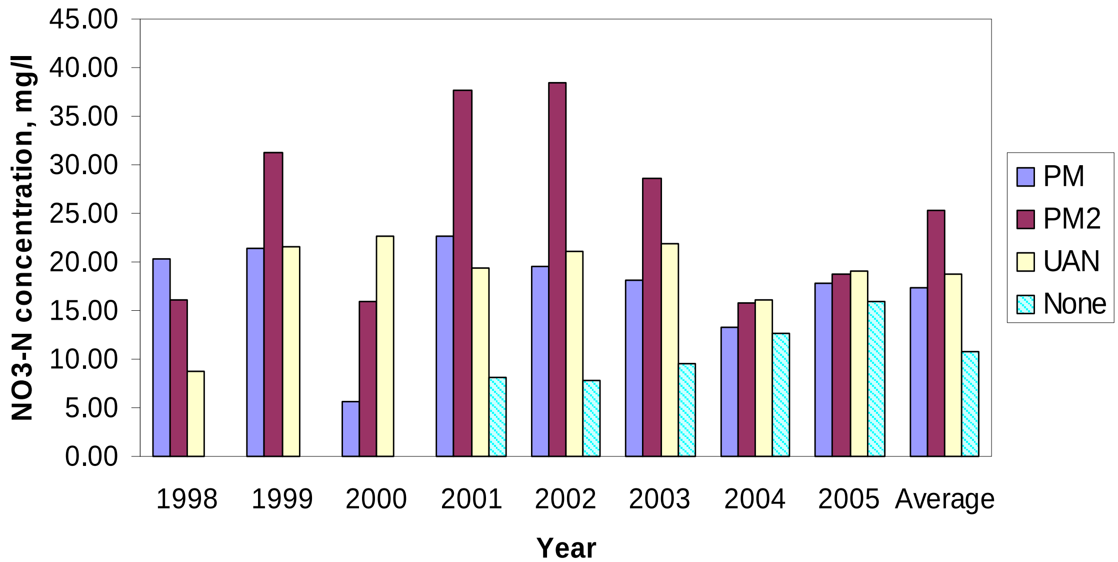

Figure 3. Average NO_3-N concentration in tile drain water as a function of treatments for eight year period (1998-2005)

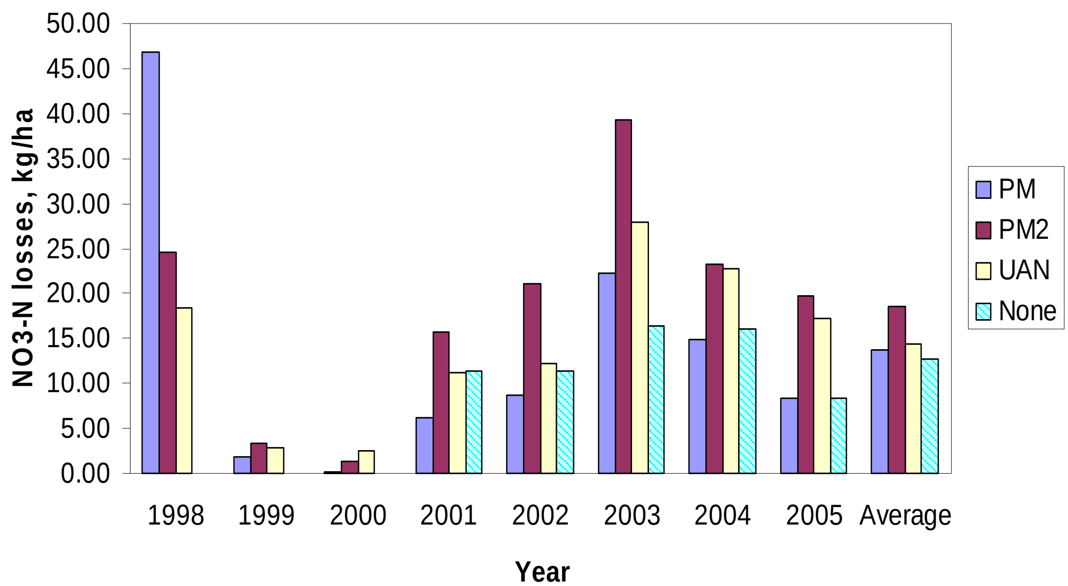

Figure 4. Average NO_3-N losses in tile drain water as a function of treatments for eight year period (1998-2005)

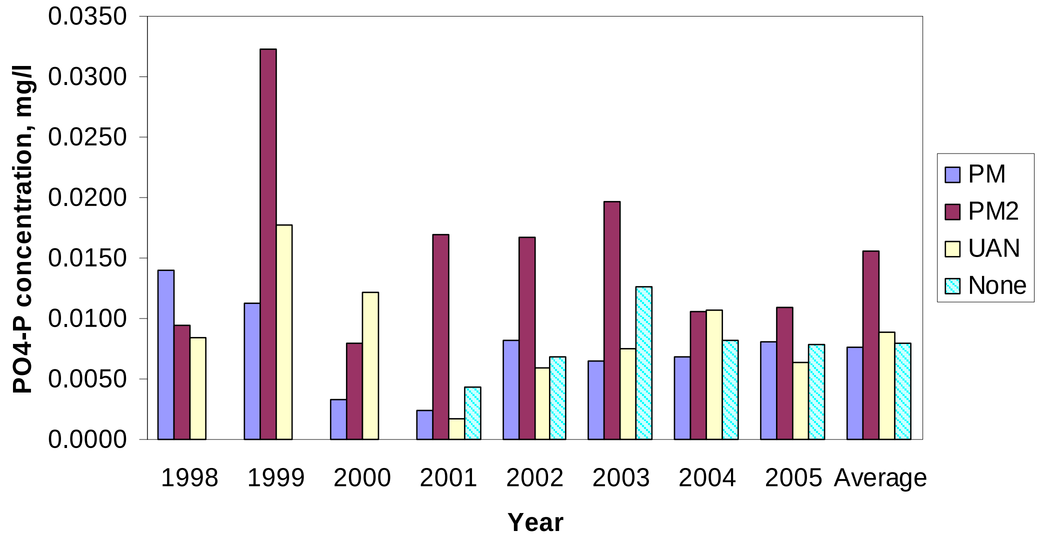

Figure 5. Average flow weight phosphorus concentration in tile drain water for eight years (1998-2005) as a function of treatments

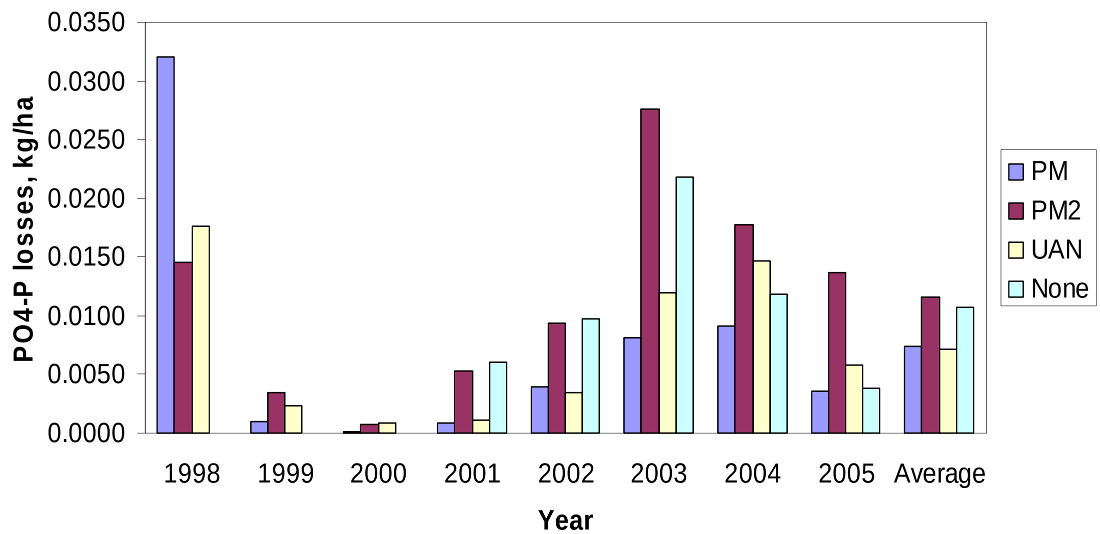

Figure 6. Average phosphorus losses in tile drain water for eight years (1998-2005) as a function of treatments

Table 4. Average of subsurface water quality from tile drain over eight years (1998-2005)

Year	Treatment	Rainfall (cm)	Tile flow (cm)	NO_3-N concentration (mg/l)	NO_3-N loss (kg/ha)	PO_4-P concentration (mg/l)	PO_4-P loss (kg/ha)
1998	PM	33.73	17.22	20.38	46.87	0.0140	0.0320
	PM2	33.73	20.97	16.05	24.65	0.0095	0.0145
	UAN	33.73	22.83	8.82	18.43	0.0084	0.0176
	None	33.73	0.00	0.00	0.00	0.0000	0.0000
1999	PM	45.19	0.86	21.47	1.89	0.0112	0.0010
	PM2	45.19	1.10	31.23	3.41	0.0323	0.0035
	UAN	45.19	1.29	21.50	2.78	0.0177	0.0023
	None	45.19	0.00	0.00	0.00	0.0000	0.0000
2000	PM	16.87	0.17	5.64	0.23	0.0033	0.0001
	PM2	16.87	0.30	15.91	1.42	0.0080	0.0007
	UAN	16.87	1.02	22.66	2.50	0.0122	0.0008
	None	16.87	0.00	0.00	0.00	0.0000	0.0000
2001	PM	52.45	3.03	22.73	6.19	0.0024	0.0008
	PM2	52.45	4.35	37.58	15.78	0.0169	0.0053
	UAN	52.45	5.95	19.31	11.24	0.0017	0.0011
	None	52.45	14.06	8.09	11.38	0.0043	0.0061
2002	PM	46.66	4.64	19.50	8.71	0.0082	0.0039
	PM2	46.66	5.38	38.40	21.00	0.0167	0.0094
	UAN	46.66	5.72	21.11	12.16	0.0059	0.0034
	None	46.66	14.41	7.85	11.31	0.0068	0.0097
2003	PM	42.55	12.4	18.17	22.17	0.0064	0.0081
	PM2	42.55	13.51	28.57	39.35	0.0197	0.0276
	UAN	42.55	12.94	21.84	27.86	0.0075	0.0119
	None	42.55	17.35	9.48	16.44	0.0126	0.0218
2004	PM	43.38	11.28	13.31	14.88	0.0068	0.0091
	PM2	43.38	13.17	15.84	23.19	0.0106	0.0177
	UAN	43.38	14.01	16.17	22.81	0.0107	0.0146
	None	43.38	22.83	12.64	16.11	0.0081	0.0118
2005	PM	55.60	4.78	17.75	8.29	0.0081	0.0036
	PM2	55.60	7.29	18.81	19.74	0.0110	0.0137
	UAN	55.60	9.07	19.03	17.26	0.0064	0.0058
	None	55.60	16.40	16.00	8.41	0.0079	0.0038
Average	PM	42.05	6.80	17.37	13.65	0.0076	0.0073
	PM2	42.05	8.26	25.30	18.57	0.0156	0.0116
	UAN	42.05	9.10	18.80	14.38	0.0088	0.0072
	None	42.05	17.01	10.81	12.73	0.0079	0.0107

CONCLUSIONS

A field study was conducted to determine the long-term effects of poultry manure on subsurface drainage water quality under a corn-soybean rotation system. Two poultry manure application rates (168 kg-N/ha and 336 kg-N/ha), one chemical fertilizer UAN application rate (168 kg-N/ha) and a control treatment (0 kg-N/ha) were used to investigate the effects of manure and UAN application on NO_3-N and PO_4-P losses with subsurface drain water. The results of this study clearly showed that the application of poultry manure at higher rate (336 kg-N/ha) gave the highest nutrient losses with subsurface drain water which eventually contaminate the surface water quality of rivers. The PM treatment was observed to have given lower tile flow and lower NO_3-N losses with tile water in comparison to other treatments over the eight years period of the study. Therefore, long-term applications at a lower rate of poultry manure of 168kg-N/ha do not have lower negative impacts on subsurface drainage water quality and could be recommended as a good practice for poultry manure management in agricultural watersheds with corn-soybean production systems.

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CHAPTER 5

LONG-TERM EFFECTS OF POULTRY MANURE APPLICATIONS ON SOIL NUTRIENT UNDER A CORN AND SOYBEAN PRODUCTION SYSTEM

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ABSTRACT

Using poultry manure as an alternative organic fertilizer in crop production would be an economical and environmental benefit to the farmers and poultry industry in Iowa. This study was aimed to evaluate the effects of long-term land application of poultry manure on soil nutrients and soil quality. Eleven field plots were used in this eight year experiment (1998-2005). The treatments included two N-based application rates of poultry manure (168 kg-N/ha and 336 kg-N/ha), one N-based rate of chemical fertilizer UAN (urea ammonium nitrate) and a check plot (no application any fertilizer). These treatment plots were laid out in a split-plot design with unbalance replications. In each field plot, corn was planted on half side of the plot and soybeans on the other half of the plot. Only the corn side of the plot would receive either the application of poultry manure or UAN fertilizer. Each half of the plot is rotated every year using a corn and soybean rotation system. Soil cores were collected to a depth of 120 cm from the ground at the beginning of the crop season (spring) and after harvest (fall) and analyzed for NO_3-N, PO_4-P (Bray-P test) and pH value. Over the eight year study, soil residue concentrations of PO_4-P and NO_3-N in the top soil layer were found to be higher under the PM2 and PM treatments in comparison with the UAN and control treatments. Also, it was found that there was a significant tendency of P accumulation in the

top layer of soil under PM2 treatment in comparison with the PM treatment. In addition, long-term applications of poultry manure have shown to increase soil nutrients (N and P) and elevate soil pH in the soil. However, further studies are needed to examine the effects of poultry manure on soil characteristics of this site and gain better understanding on biological and chemical soil properties.

Keywords: poultry manure management, residual soil NO_3-N and PO_4-P, corn-soybean rotation, chemical and biological properties of soil.

Abbreviation:

PM (poultry manure application at 168 kg-N/ha), PM2 (poultry manure application at 336kg-N/ha), UAN (Urea Ammonium Nitrate application at 168 kg-N/ha)

INTRODUCTION

With a rich organic nutrient source, animal manure can be an alternative organic fertilizer for crop production for perennial forages (i.e. corn, wheat) instead of being treated as a solid waste that could potentially pollute the environment. Among the available sources of animal manure, poultry manure generally has a higher content of N, P_2O_5 and K_2O_5 both in liquid and non-liquid form in comparison to other types of animal manures (beef, turkey, dairy and swine) (USDA-ARS, 2005). Thus, using poultry manure in crop production could bring more benefit for farmers by decreasing use and reducing cost of chemical fertilizers. The use of poultry manure can help to improve soil quality. In Iowa, over 0.5 million tons of poultry manure is produced every year; thus, land application of poultry manure in corn-soybean systems can be environmentally friendly and an economical solution for the poultry industry and farmers. So far, much of the research has focused on the effects of using animal manure in agriculture on crop production, soil nutrient, environment quality (surface and subsurface water, air quality) and human health (Wang et al. 1998). Other public concerns were on the transport of pathogen microorganisms into water bodies, the eutrophication with the increase in nutrient (N, P, K) amounts in water bodies from agricultural lands receiving manure for crop production (Warnemuende and Kanwar, 2002).

For land application of manure in agriculture, the method, timing of application, and application rates have been extensively studied under different cropping systems. Pote et al. (2003) studied the effects of incorporating poultry litter on nutrient losses and erosion with runoff water. The findings from this experiment showed that the improvements in soil properties (infiltration capacity, sediment retention, and water holding capacity) in field plots receiving poultry manure in comparison with those applied with chemical fertilizer or without having incorporation of poultry manure. Another significant finding was the application of poultry manure increased crop yield and the incorporation of manure (knifing technique) helped to reduce 80% nutrient and sediment losses with runoff water under rainfall simulation experiments. However, the amount of NO_3-N and PO_4-P losses via leaching and the contribution of NO_3-N and PO_4-P in the soil profile from previous crop seasons was not mentioned and taken into consideration in this study. Stevens et al. (2005) suggested to avoid applying excessive N fertilization and pointed out that long-term land application of poultry manure at high rates (201 and 268 kg-N/ha) decreased the response to crop growth and increased the mineralization of N residue from the previous year applications which consequently promoted more N losses to surface and ground water. The increase in nutrient losses through leaching and volatilization at high manure application rates were observed in a 20 year experiment (Chang and Janzen,1996).

Poultry manure was also found to be more effective than chemical fertilizer (UAN or other ammonium fertilizer) in terms of reducing P in runoff and NH_3 volatilization (Moore and Edwards, 2005; Moore et al., 2000). The results of this long term study (20 years) proved that poultry manure and alum treated poultry litter would have consistently higher crop yields, lower P-soil losses with runoff water and higher soil pH than unfertilized or chemically fertilized field plots. With the increase in pH value of soil, poultry litter treatments prevented the acidification of soil in a long-term study in comparison to using NH_4-NO_3 as a fertilizer. Whalen et al. (2000) arrived at similar conclusions about the increasing pH in acid soils by adding cattle manure in a short-term experiment. Gilley and Risse (2000) reported that runoff and soil losses due to erosion from manure treated plots under different cropping systems and management practices were respectively 2 – 62% and 15 – 65 % lower than those receiving chemical fertilizer or no fertilizer applied at all. Tejada et al. (2006) showed that land application of poultry manure combined with crush cotton, gin compost on corn fields recovered the degraded soil in a semiarid region by enhancing the biological properties of the soil after four years. Another source of NO_3-N and PO_4-P from crop residue contributed significantly to soil nutrients and the nutrient losses in runoff (Cermark et al., 2004). Under an extensive laboratory study on leaching and sorption ability of corn, soybean and winter wheat residues towards NO_3-N and PO_4-P, the authors found that after one year , corn and soybean residues leached PO_4-P ranging from 15 to 527 mg/g and 23-256 mg/g, respectively and NO_3-N ranging from 7 to 55 mg/g. These results indicated that corn and soybean residues could contribute significantly to nitrate and phosphorus to soil and increase leaching with runoff water.

Generally, the application rates of poultry manure are N based rather than P based; therefore, there is a trend to accumulate P and K in soil profile under continuous applications of year after year. The excess P built up in soils increases the potential to contribute soluble and particulate P to surface waters (Daverede et al., 2003; DeLaune et al., 2004). For example, Ferguson et al. (2004) compared the long-term effects of N-based and P-based manure application rates on corn fields and found that P-based rates had lower silage yield and crop nutrient removal than N-based manure application rates. In another study about challenges of using swine manure, Karlen et al. (2004) recommended that the P-based application rates rather N-based rates should be used for Iowa cropping systems treated with swine manure to reduce high P accumulation in soil profile after long-term manure application. Soil phosphorus profile data was used to evaluate the potential of phosphorus leaching from field plots treated with manure (Kleinman et al., 2003).

Most of the previous studies conducted on corn and soybean cropping systems were done using corn after soybeans or intercropping corn and/or soybeans with alfalfa, winter ryes, oats, or grain sorghum, cotton etc. (Lesoing and Francis, 1999; Kanwar et al., 2005; Russelll et al., 2005; Mitchell and Tu, 2005). However, for the corn and soybean system, the information of effects of long-term poultry manure application on soil nutrient was not fully understood. Therefore, the overall objectives of this study were to (i) characterize the long-term effects of poultry manure application rates (168kg-N/ha and 336 kg-N/ha) on the changes of NO_3-N and PO_4-P in soil, and (ii) evaluate the positive and negative effects of poultry manure vs. chemical fertilizer (UAN) on soil nutrients after long-term land applications. Theoretically, soils receiving poultry manure are hypothesized to have better chemical properties than unfertilized or chemically fertilized soils. An implicit assumption used in this study was the improvement of soil chemical and biological properties under manure application. However, future studies will be conducted on changes in soil organic matter, soil cation exchange capacity (CEC), and hydraulic conductivity to gain a deeper insight the long-term effects of poultry manure on soil properties.

MATERIALS AND METHODS

Field experiments were conducted from 1998 to 2005 at the Iowa State University's Agronomy and Agricultural Engineering Research Center near Ames, Iowa. The site is located on Nicollet loam soil formed in glacial till under the prairie vegetation with the organic matter content of about 4% and a maximum slope of 3%. Nicollet soils are characterized as moderately permeable, somewhat poorly drained, produce surface runoff; have high available water holding capacity, and seasonal high water tables (Chinkuyu et al., 2002; Cheatham, 2003). Nine field plots drained by a single subsurface tile drain in the middle of each field plot were used in this experiment. These tile drains were intercepted at the end of each field plot and a V-notch and sump installed for water quality sampling. The size of each field plot varied from 0.19 ha to 0.42 ha. The map of the field plots is shown in Figure 1. One-half of each field plot (where corn was grown in previous year) was tilled every fall using a chisel plow, which ensured that about 30% of the crop residue was left on the surface. Corn (*Dekalb 580*) was planted on one half of each field plot and soybean (*Kruger 2426*) on the other half of the same. Either poultry manure or UAN fertilizer was applied on the corn side in each field plot. Poultry manure (PM) was applied at two different rates (168kg-N/ha and 336kg-N/ha) and UAN fertilize (NH_4NO_3) was applied at a rate of 168kg-N/ha using surface broadcast methods, and then incorporated into the soil with in 48 hours by tilling the soil down to the depth of about 15 cm to reduce the loss of nitrogen via volatilization. A control plot, receiving 0 kg-N/ha, was also established. Three poultry manure samples were collected and sent to the lab for analyzing the content of N, P and K in manure composition to determine the actual N application.

Three soil core samples were randomly collected to a depth of 120 cm in each field plot before applying manure, usually before planting (Spring samples) and after harvesting (Fall samples). The soil sampling was done only on the corn side in all field plots. Soil samples were taken using zero contamination tubes and a girding probe. Soil core samples then were transferred immediately to freezer until being processed for NO_3-N and PO_4-P concentration analyses in the laboratory.

Laboratory analysis of soil samples

Each soil core was cut into five different soil depths (0-15; 15-30; 30-61; 61-91 and 91-120 cm) corresponding to five depths in the soil profile of each field plot. For each field plot, the three separate samples for each depth were mixed together to give one composite soil sample for each depth and stored in plastic bags. Soil bags were then sent to the Agronomy Soil Lab, Iowa State University for analyses for NO_3-N and PO_4-P (Bray-P test) concentration and pH.

Experimental design and data analysis

The experimental treatments in this study were two application rates of poultry manure (PM: 168 kg-N/ha, and PM2: 336 kg-N/ha) with three replications for each rate; one application rate of UAN (167 kg-N/ha) with four replications and one non-fertilized check plot (None: 0 kg-N/ha). These treatments were assigned on eleven field plots in a split-plot design with unbalance replications. Rotation effects were nested in crop years (1998-2005). Analysis of variance (ANOVA) was performed to determine the significance of differences between the means (NO_3-N and PO_4-P concentration and pH value in the soil profile as a function of depth and application rates) using SAS software (SAS Institute Inc., 2001). Differences among treatment means were separated using the Fisher's least significant difference procedure. A paired-t test (p=0.05) was conducted to compare the difference in soil nutrient between Spring and Fall soil samples. In all of the statistical analyses, a significant level $\alpha = 0.05$ was used to evaluate the significant difference of all hypothetical testing.

RESULTS AND DISCUSSION

Manure characteristic and application rates

Poultry manure used in this experiment was obtained from a laying hen farm in Humboldt, Iowa. Three manure samples were collected during the time of application and analyzed for manure characteristics (total moisture content, K, NH_3, TKN, and total P). Table 1 gives the poultry manure characteristics during the experiment period (1998-2005). Data in Table 1 indicated that there was a fluctuation in manure nutrient contents during the period of study and that partially helped to explain the difficulty to achieve the target N application rates. Theoretically, the target application rates of poultry manure were 168 kg-N/ha and 336 kg-N/ha; however, due to variable manure characteristics at the time of manure collection and by the time of manure application, significant changes in nutrient contents of poultry manure have occurred every year. Therefore, the actual N application rates over eight years were higher than the target application rates (Table 2). In all years, the amount of N in manure lost during application was assumed to be about 5 percent of the total N in the manure. The average actual application rates varied from 202 kg-N/ha to 375 kg-N/ha for the low and high application rates, respectively. Such changes in application rates could have significant effects on soil nutrient contents (nitrogen and phosphorus residue in soil); and soil acidity and the availability of nitrogen and phosphorus in top layers of soil profile under long-term applications of poultry manure (Bahl and Toor, 2002; Yang et al., 2004; Stevens et al., 2005 and Moore and Edwards, 2005).

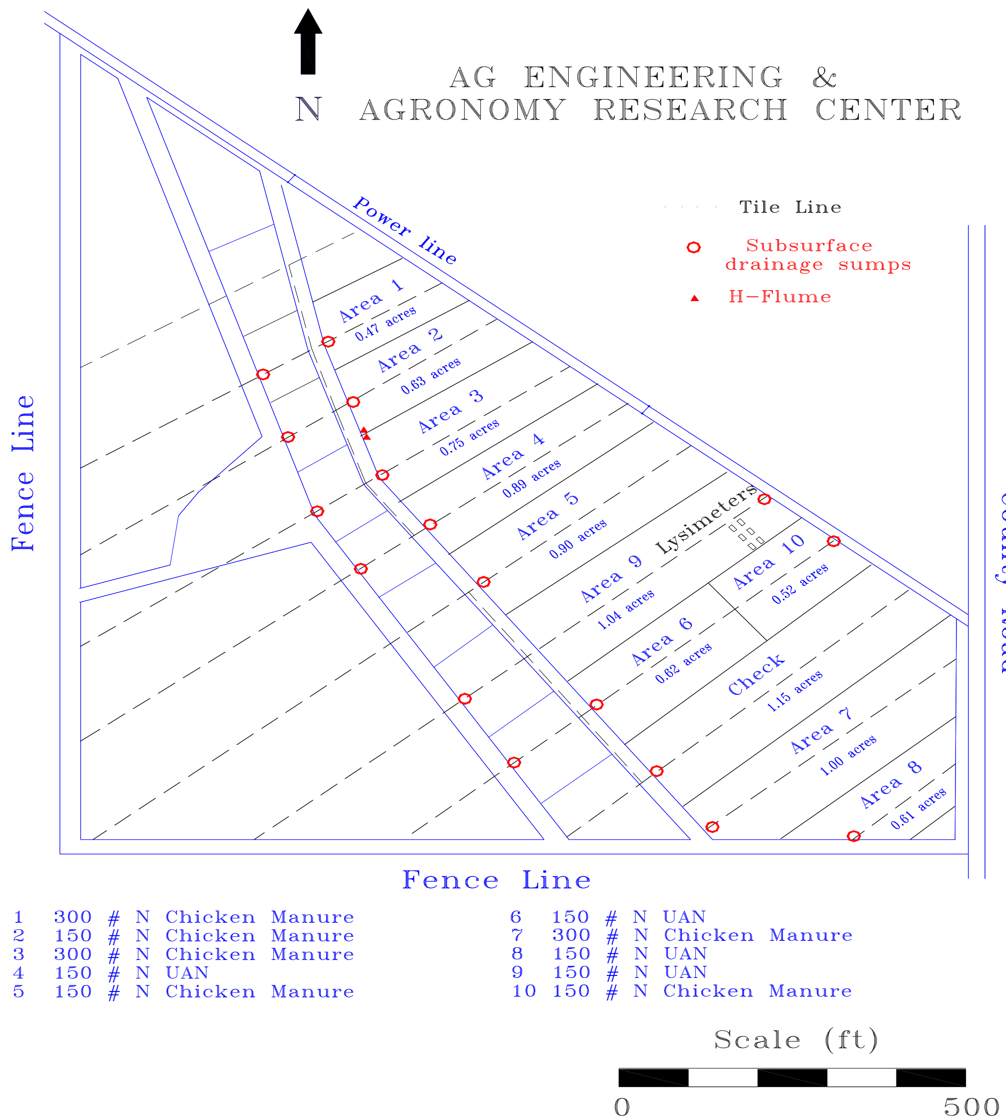

Figure 1. Field plots laid out for poultry manure experiment at the Iowa State University Agronomy and Agricultural Engineering Research Center

In the future study on this experiment, the actual application rates will be kept closer to 168 kg-N/ha and 336 kg-N/ha for two poultry manure treatments to give low and high N application rates comparison purposes.

Long-term effects of poultry manure application on soil acidity

Several studies have shown that long-term application of poultry manure would improve the acidity of soil and help to neutralize the soil pH especially for acid soil (Whalen et al., 2000; Vadas et al., 2004). Soil acidity might be corrected by using manure instead of lime or gypsum because the materials such as Ca and Mg contained in manure help to increase the soil pH over short-term and long-term applications (Whalen et al., 2000; Stevens et al., 2005). Therefore, the soil pH was investigated in this study as a measure of the improvements in soil quality at the 6^{th} and 7^{th} year of the experiment (2003-2004). Figure 2 presented the initial soil pH in the soil profile at five different depths from Spring soil test (normally before applying manure) at the beginning of the crop season (2003 and 2004). The changes in soil acidity in the soil profile at the end of crop season (after harvesting) are presented in Figure 3. The results in Figures 2 and 3 showed that there was not much change in soil pH in the top soil layers (0-15 and 15-30 cm) between Spring soil test and Fall soil test in all treatments although the PM and PM2 treatments slightly elevated the soil pH in the top soil layer. However, there was a significant increase in pH values at two deeper depths (61-91 and 91-120 cm) ($p<0.001$) at the end of crop season in fertilized field plots (PM, PM2 and UAN treatments) (Figure 4). Further investigations at this study site could be made on the soil organic content in manure treated plots because applying manure over long period could potentially increase soil organic matter (SOM) and in turn, the buffer capacity of SOM affects the soil acidity and other physical and biological soil properties (Risse et al., 2006).

Table 1. Characteristics of poultry manure applied to field lots over eight years

	1998	1999	2000	2001	2002	2003	2004	2005
Total Kjedhal N (TKN), % N	1.49	3.04	2.69	2.16	1.41	2.03	2.36	2.04
Ammonia (NH3), %N	1.00	4.37	3.94	2.72	2.24	1.60	1.59	0.20
Total Phosphorus, %P	1.43	2.29	2.41	2.62	1.20	1.81	2.08	1.66
Potassium, %K	1.11	0.74	0.72	8.50	0.57	1.71	1.13	0.82
Moisture Content, %H2O	48.12	45.03	32.60	56.97	53.70	76.25	69.93	27.70

Table 2. Eight year average manure application rates for field plots (1998-2005)

	168 kg N/ha poultry manure				336 kg N/ha poultry manure			
	Average manure application rate, (kg/ha)	Average application rate, (kg/ha)			Average manure application rate, (kg/ha)	Average application rate, (kg/ha)		
Year		**N**	**P**	**K**		**N**	**P**	**K**
1998	10674	159	106	152	24190	364	228	303
1999	9575	291	418	220	14774	440	622	275
2000	3213	86	127	77	8741	326	328	196
2001	8998	195	244	115	14957	324	407	192
2002	7982	249	179	95	14295	377	321	171
2003	11318	229	182	205	18231	369	291	331
2004	7739	230	202	110	15446	458	404	220
2005	6960	178	146	72	13377	343	279	138
Average	**8307**	**202**	**200**	**131**	**15501**	**375**	**360**	**228**

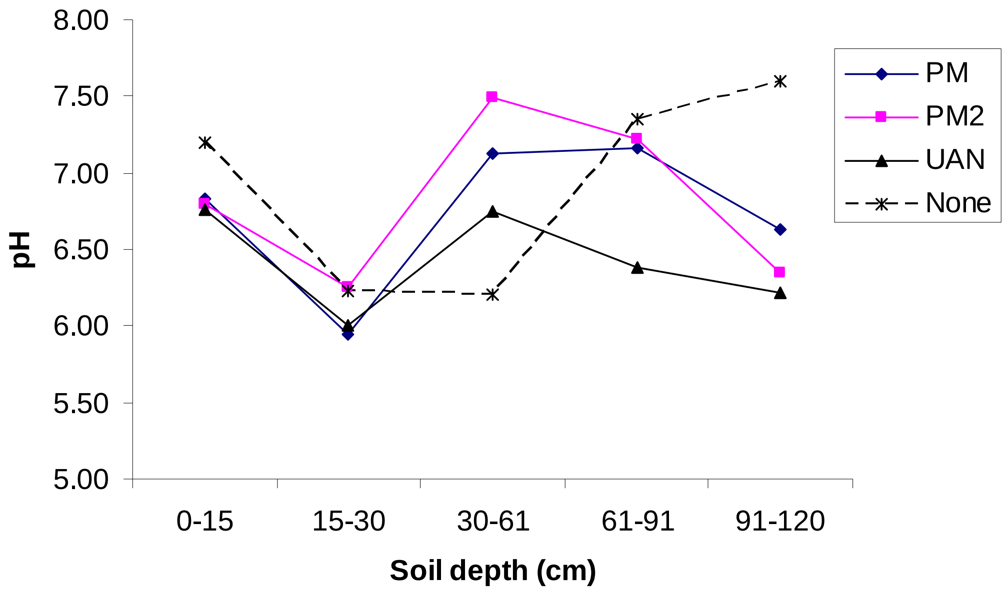

Figure 2. Average soil pH at different soil depths for Spring soil test at the beginning of crop season (2003 and 2004).

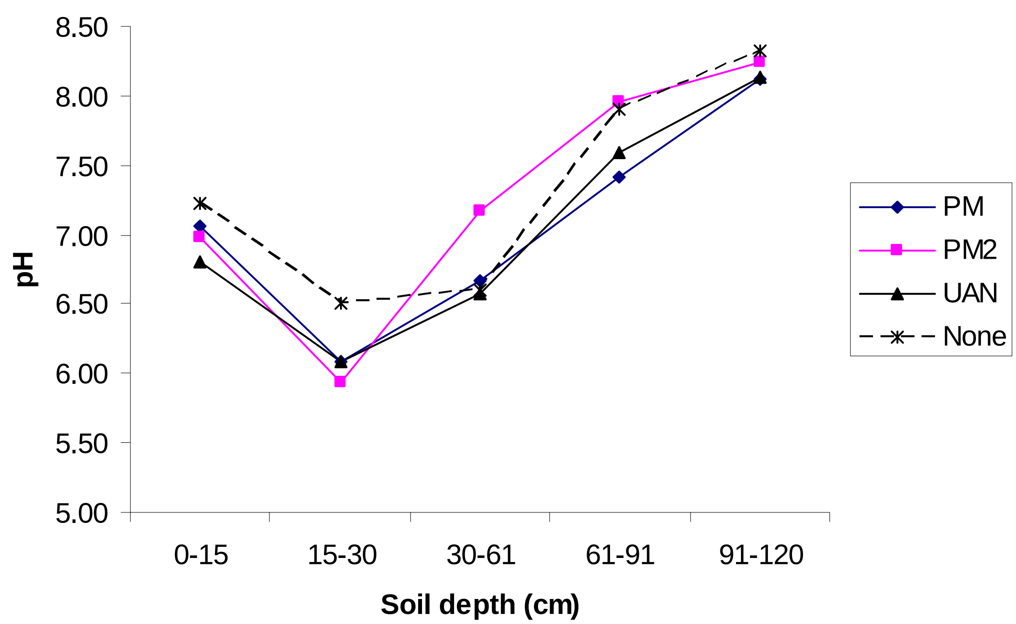

Figure 3. Average soil pH at different soil depths after harvesting for Fall soil test (2003 and 2004)

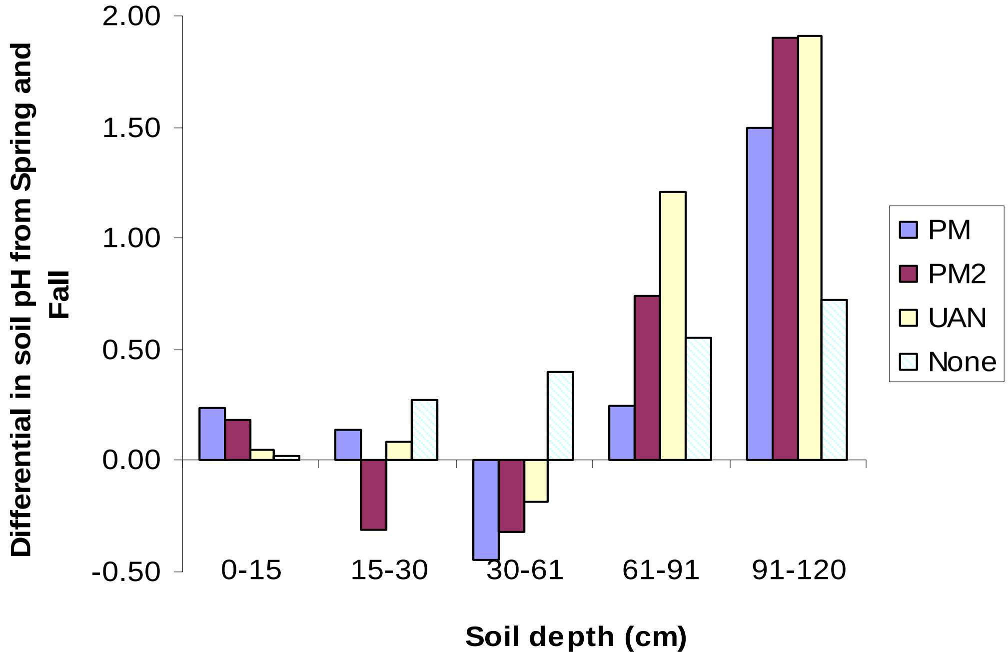

Figure 4. Average differences in soil acidity at soil depths before and after the crop season (2003 and 2004)

Long-term effects on NO_3-N concentration in soil profile

Initial condition of soil NO_3-N before applying treatment at the beginning of crop season (1998-2005) was presented in Figure 5a. The average soil NO_3-N residual concentrations at the end of growing season as a function of soil depth and type of fertilizer are presented in Figure 5b. The treatment effects of fertilizer application on residual soil NO_3-N concentrations in top two soil layers (0-15 and 15-30 cm) are given in Table 3. The data given in Figures 5a,b and Table 3 indicated that there was a significant effect of fertilizer application ($p< 0.001$) on soil NO_3-N concentrations in two top soil layers (0-15 cm and 15-30 cm) for both Spring and Fall soil tests. However, the soil NO_3-N concentrations at different lower depths were observed to be not much different from before fertilizer application and after harvesting. The Figures 6a,b and Figures 7a,b show the temporal variability in residual soil NO_3-N concentration as a function of fertilizer types in top two soil layers (0-15 cm and 15-30 cm) from Spring and Fall soil tests (1998-2005). These results showed that there was a significant difference in residual soil NO_3-N concentration in top soil layer for all treatments ($p< 0.0001$) in both Spring and Fall. Besides, at higher rates of manure application, residual soil NO_3-N concentration were higher than those of lower manure application rates (Table 3) which might be subject to nutrient losses with runoff water and leaching to groundwater. Table 3 shows that there is larger decrease in residual soil NO_3-N concentration from 0-15 to 15-30 cm soil layer for UAN treatment in comparison with PM and PM2 treatments for Spring test. This implied that much of the applied and residual NO_3-N amount in the soil may have been lost to leaching during the crop season rather than kept in the soil from UAN treatment in comparison with PM and PM2 treatments. Also, a higher residual NO_3-N concentration in top soil layer shows high availability to crop uptake in PM and PM2 treatments. In another study on residual nitrate in soil at two Iowa State University research and demonstration farms in Ames and Nashua, Iowa, Al-Kaisi and Licht (2004) observed similar results for NO_3-N movement in soil profile at similar depth intervals with the application rate of 170 kg-N/ha. This study was conducted for 2 years (2001-2002); therefore, the effect of climate changes over a long-term period on NO_3-N movement was not revealed. The increase in residual soil NO_3-N with the increase of N application rate was also reported by Bar-Tal et al. (2004) after annually applying manure on wheat.

Table 3. **Average NO_3-N concentration in top soil layers in response to type of fertilizer and application rates in eight years (1998-2005)**

Treatments	Spring		Fall*		Difference (Spring vs. Fall)	
	NO_3-N concentration, ppm					
	--------------Soil depth--------------					
	0-15** (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)
PM (168 kg-N/ha)	19.5[a]	9.4[a]	12.6[a]	7.5[a]	6.9	1.9
PM2 (336 kg-N/ha)	19.6[a]	10.2[ab]	15.7[b]	11.5[b]	3.9	-1.3
UAN(168 kg-N/ha)	25.2[b]	11[b]	11.2[a]	8.0[a]	14.0	3.0
None (0 kg-N/ha)	15.5[c]	8.3[a]	7.5[c]	6.1[a]	8.0	2.2

*Fall soil test results are available for seven years (98-04)
**Values in the same column followed by the same letter were not significantly different at significant level $\alpha = 0.05$.

Table 4. Average PO_4-P concentration in top soil layers in response to types of fertilizer and application rates over time (1998-2005)

Treatments	Spring		Fall*		Difference (Spring vs. Fall)	
	PO_4-P concentration, ppm					
	--------------Soil depth--------------					
	0-15** (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)	0-15 (cm)	15-30 (cm)
PM (168 kg-N/ha)	59.95[a]	11.18[a]	61.54[a]	11.13[a]	1.58	0.04
PM2 (336 kg-N/ha)	66.85[b]	14.11[b]	85.72[b]	11.05[a]	18.87	3.06
UAN(168 kg-N/ha)	33.44[c]	12.81[c]	30.14[c]	8.75[b]	3.30	4.06
None (0 kg-N/ha)	20.75[d]	6.69[d]	25.07[d]	7.00[b]	4.32	0.31

* Fall soil test PO_4-P concentration was available for 7 years (1998-2004)
** Values in the same column followed by the same letter were not significantly different at significant level $\alpha = 0.05$

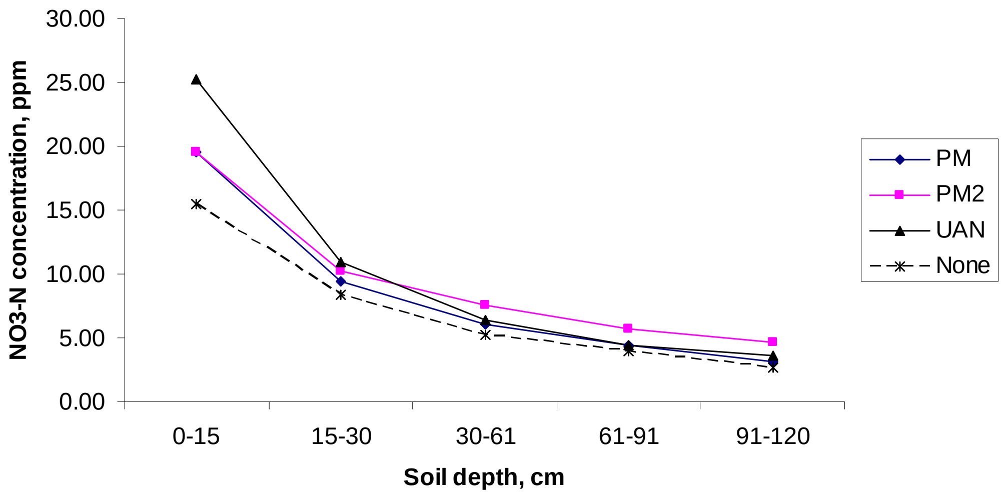

Figure 5a. Average NO_3-N concentration in soil profile for Spring soil test (98-05)

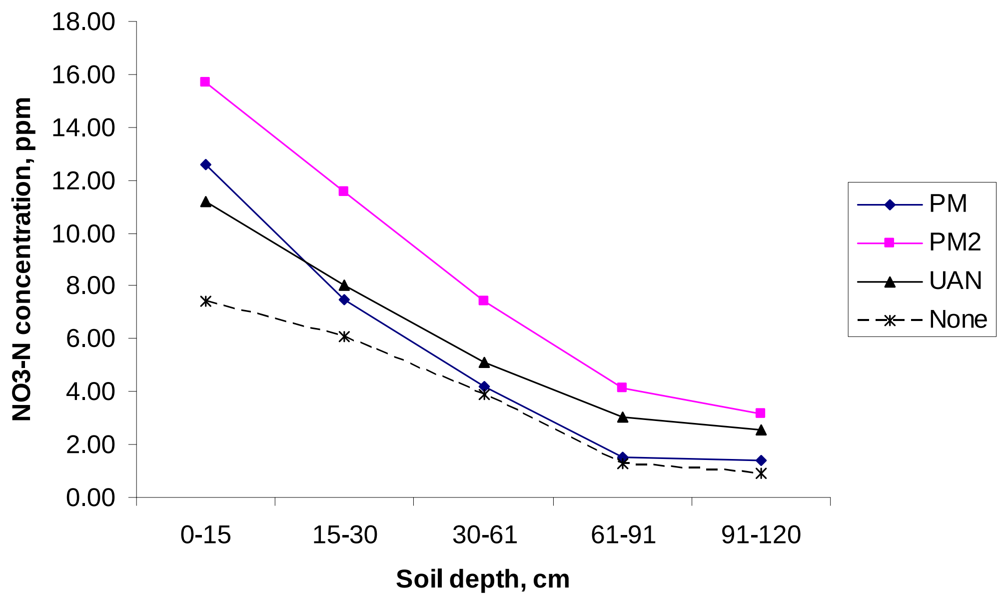

Figure 5b. Average NO_3-N concentration in soil profile for Fall soil test (98-04)

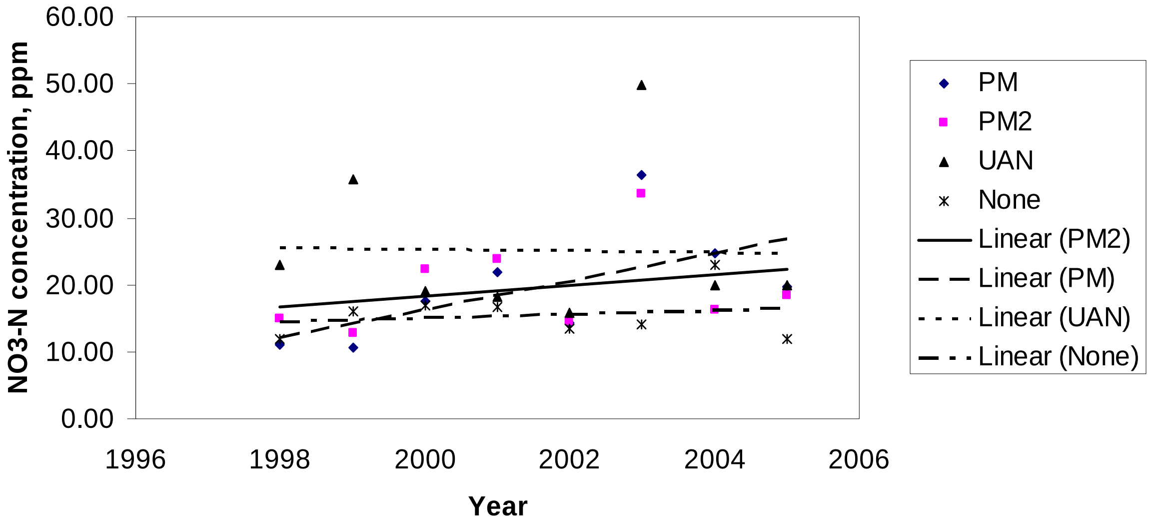

Figure 6a. Temporal variability in NO_3-N concentration in the top soil layer (0-15 cm) as a function of fertilizer types for Spring soil test

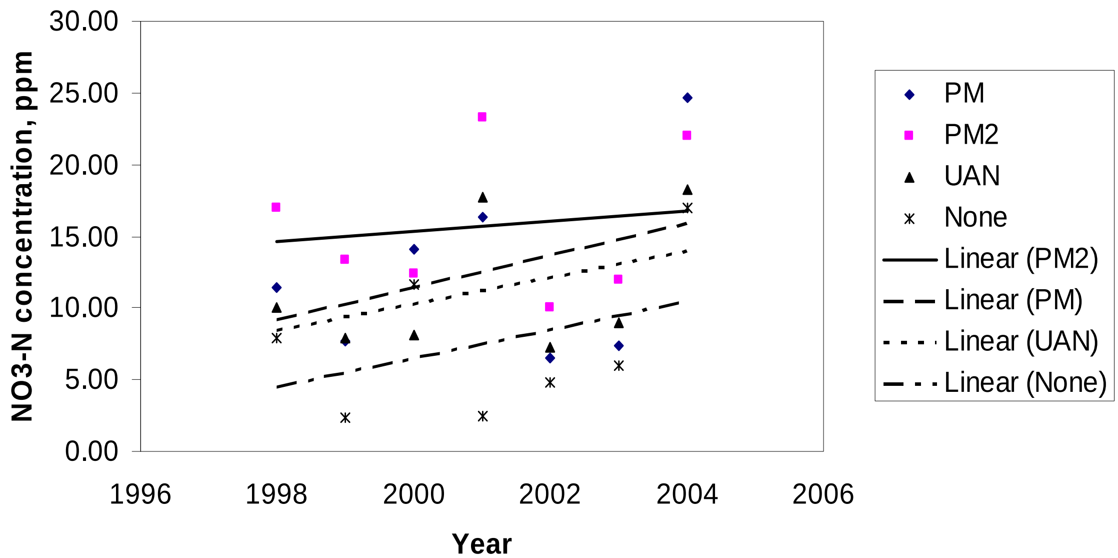

Figure 6b. Temporal variability in NO_3-N concentration in the top soil layer (0-15cm) as a function of fertilizer types for Fall soil test

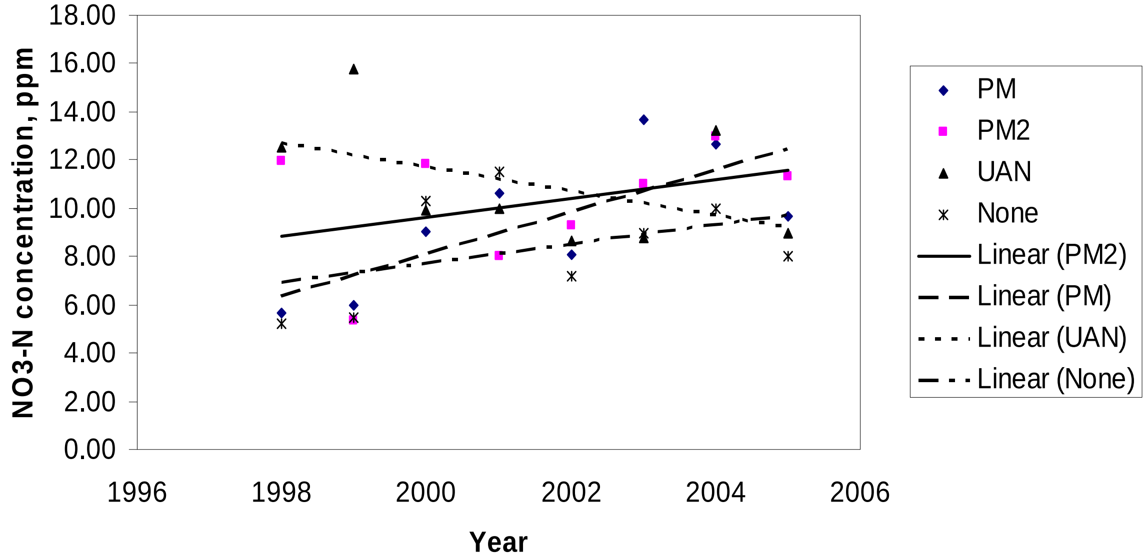

Figure 7a. Temporal variability NO_3-N concentration in the top soil layer (15-30 cm) as a function of fertilizer types for Spring soil test (1998-2005)

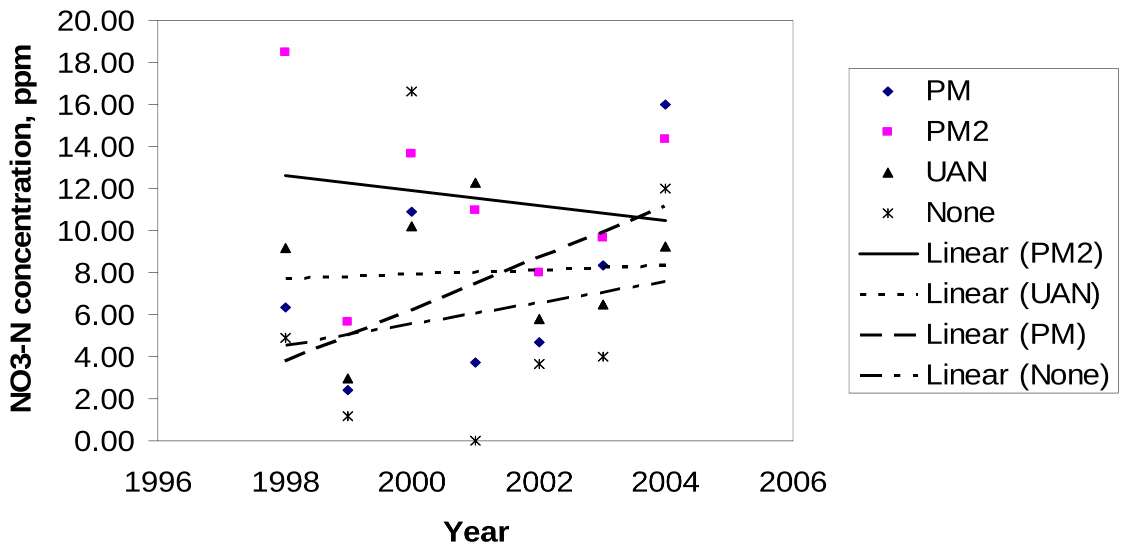

Figure 7b. Temporal variability NO_3-N concentration in the top soil layer (15-30 cm) as a function of fertilizer types for Fall soil test (1998-2004)

Long-term effects of manure applications on PO_4-P concentration in soil profile

With high P contents in poultry manure and due to a N-based rate applications, higher soil residual PO_4-P concentration was expected to build up in the top soil layer under PM and PM2 treatments. The average soil PO_4-P concentration as a function of soil depth and type of fertilizer is presented in Figures 8a,b for Spring and Fall soil tests, respectively. Similar to the results on soil NO_3-N concentrations, there was a significant difference in soil PO_4-P concentration in top soil layers (0-15 and 15-30 cm) from those of the other lower layers ($p < 0.0001$) in both Spring and Fall soil tests. The PO_4-P concentration was observed to decrease with soil depth and increase with application rates ($p < 0.001$). The means of soil PO_4-P concentration from PM2 and PM treatment was almost two times as high as that of UAN treatment for the top soil layer (0-15 cm). Higher PO_4-P in top soil layer in Spring soil test also implied that there might exist the release of PO_4-P from crop residue into soil after the crop season in addition to P accumulation capacity of soil. The results of temporal variability of PO_4-P concentration on top soil layers (0-15 and 15-30 cm) are presented in Figures 9a,b and Figures 10a,b, respectively. In both cases, the trend in soil PO_4-P concentration in PM2 and PM treatments at the end of the crop season showed an increase over time in the rank as followed: PM2>PM>UAN>None for 0-15 cm soil layer and PM2>UAN>PM>None for 15-30 cm soil layer. However, the difference between UAN and PM treatments was not significant for 15-30 cm layer soil (Table 4). These results also indicated that there was a significant trend to accumulate P in top the soil layers under PM2 treatment in comparison with the other treatments in both Spring and Fall soil tests. Thus, using a PM treatment for a corn-soybean production system would help to increase soil nutrient and reduce the risk of elevated P levels in soil profile under long-term manure applications. Besides, the interaction effect of crop rotation and the treatments was found significant ($p < 0.0001$) for the PO_4-P concentration in the top soil layer towards PM and UAN treatments in comparison with the PM2 treatment over the eight year period (1998-2005). This suggested that the poultry manure application under the current corn and soybean rotation might help to increase the PO_4-P available for crop use in the following season.

CONCLUSIONS

A field experiment was conducted to evaluate the long-term impacts of poultry manure on the status of N and P build up in the soil under a corn and soybean production system in Iowa. After an eight year study, the application of poultry manure at a lower application rate of 168kg-N/ha was found to be more beneficial to soil properties in comparison with the application of UAN in terms of increasing NO_3-N and PO_4-P available in soil for crop use in the following growing season as well as reducing the risk of build up PO_4-P in soil profile under higher poultry manure application rate of 336 kg-N/ha. The results of the study indicated that applying poultry manure at low rate (168 kg-N/ha) also helped to neutralize soil acidity in the top soil layer which in turn would improve the chemical, physical and biological soil properties under long-term applications. Finally, the results of this study also showed that future studies should concentrate on monitoring soil organic matter and other soil properties at this site in order to gain a better understanding of the beneficial use of poultry manure.

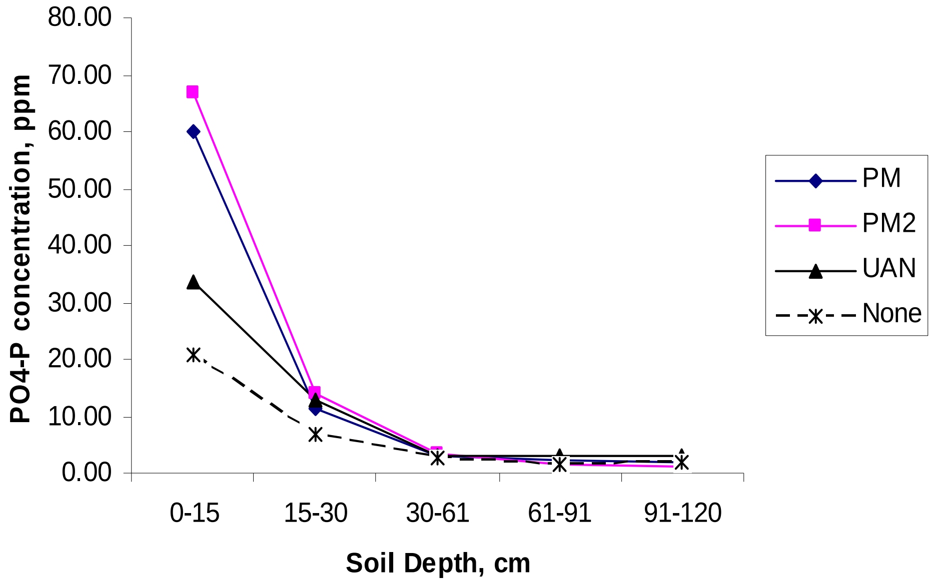

Figure 8a. Average PO_4-P concentration as a function of soil depth and fertilizer types in Spring soil test (1998-2005)

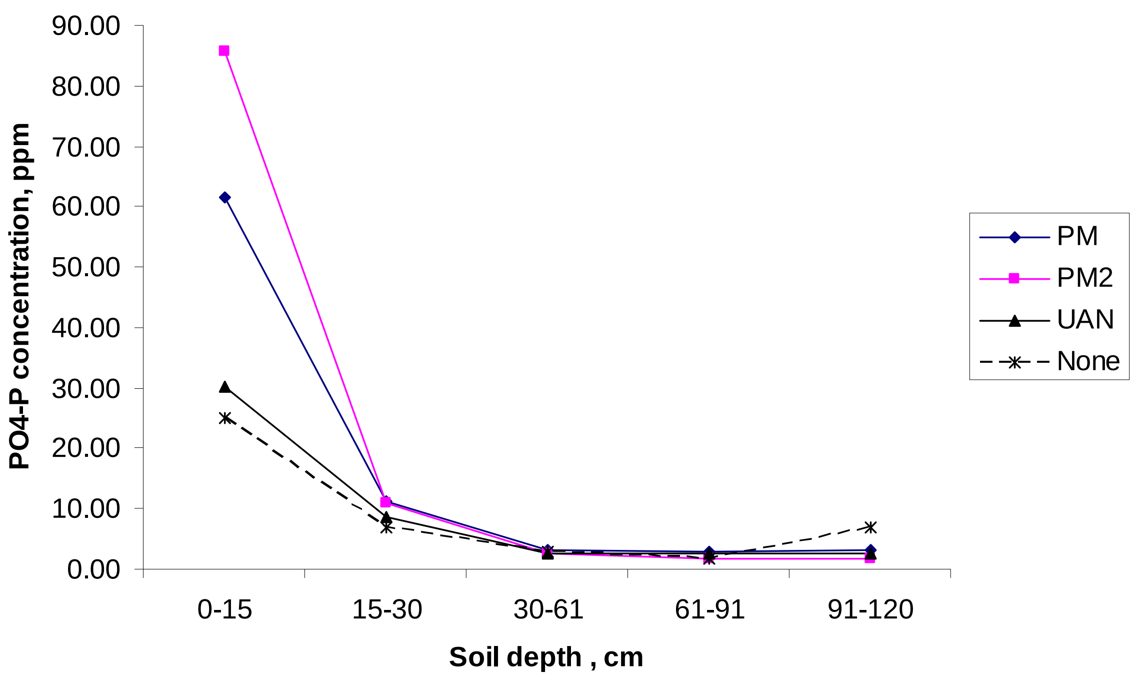

Figure 8b. Average PO_4-P concentration as a function of soil depth and fertilizer types after harvesting in Fall soil test (1998-2004)

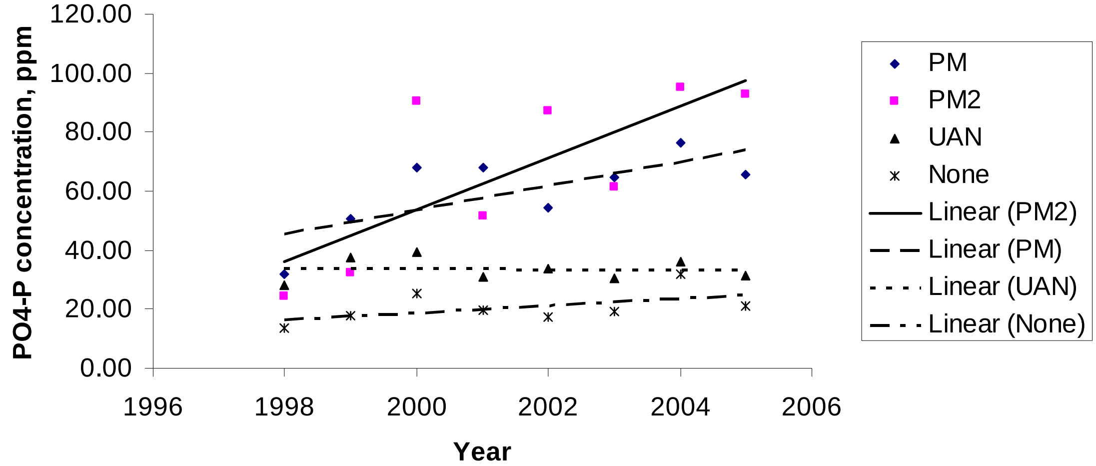

Figure 9a. Temporal variability in PO_4-P concentration on top soil (0-15 cm) in different fertilizer types before applying manure in Spring soil test

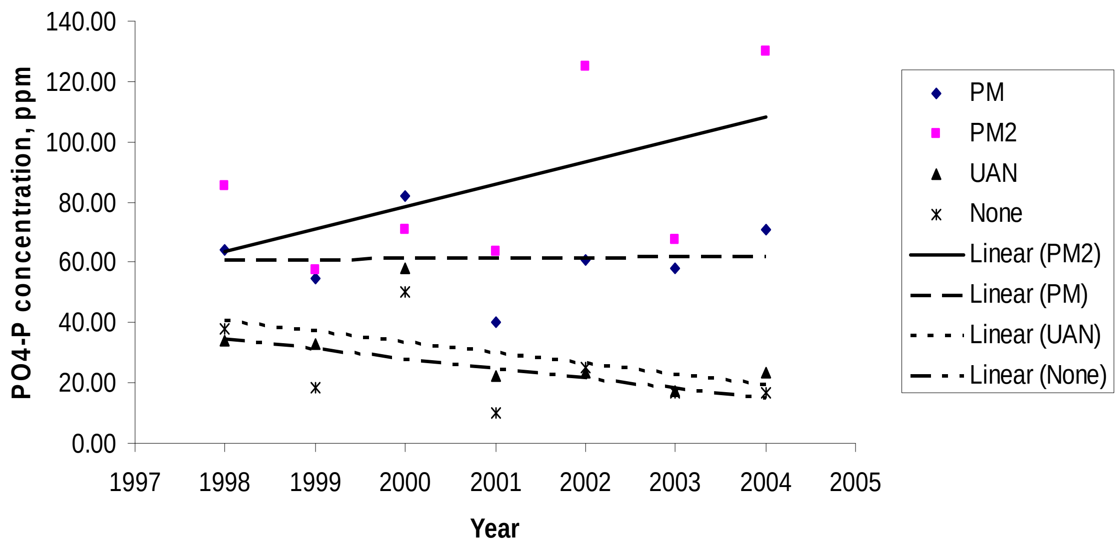

Figure 9b. Temporal variability in PO_4-P concentration on top soil (0-15 cm) in different fertilizer types after harvesting in Fall soil test

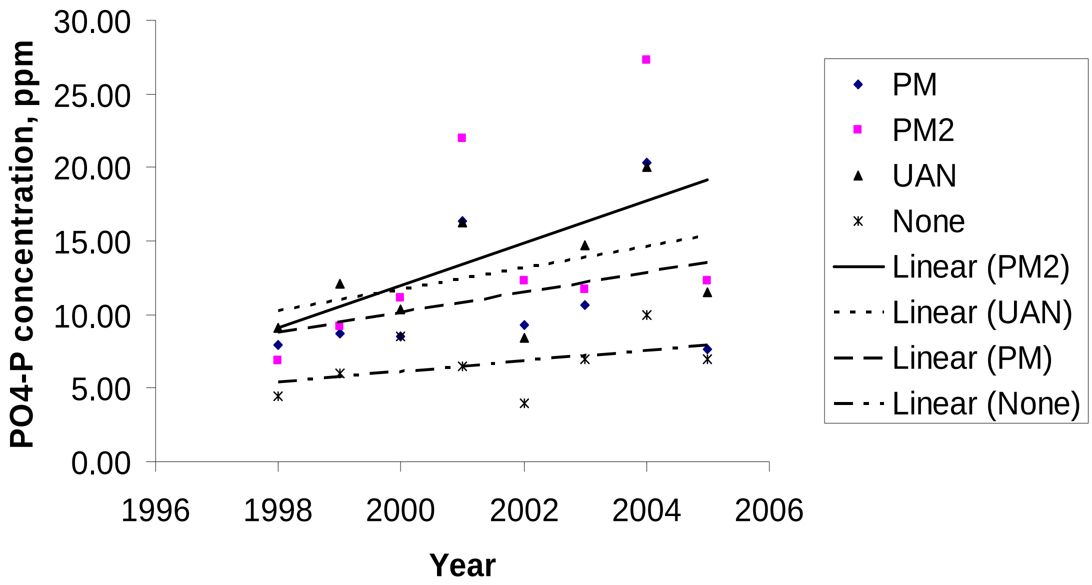

Figure 10a. Temporal variability in PO_4-P concentration on top soil (15-30 cm) in different fertilizer types for Spring soil test before crop season

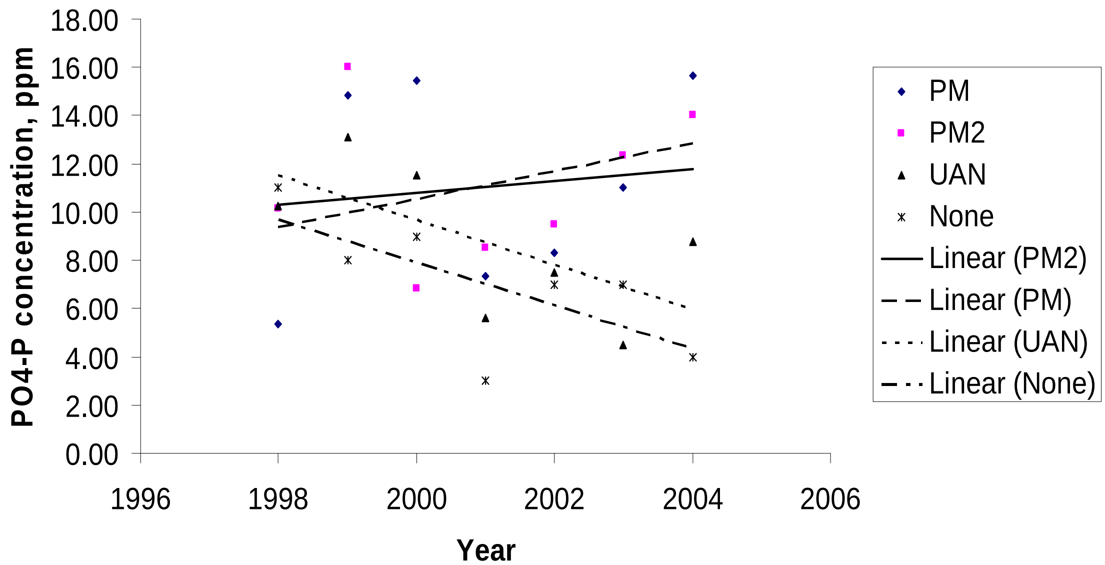

Figure 10b. Temporal variability in PO_4-P concentration on top soil layer (15-30 cm) in different fertilizer types for Fall soil test after harvesting

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CHAPTER 6: GENERAL CONCLUSIONS

With fast development in the poultry industry in Iowa during the past few years, there is a public concern on the large volume of poultry manure produced and its effects on air and water quality. Land application of poultry manure for crop production is one of the best solutions for large volumes of poultry manure produced in Iowa. A long-term study was conducted for eight years (1998-2005) to evaluate the effects of poultry manure on crop yields, subsurface drainage water quality and residual soil N and P concentration. The field experiments investigated the effects of poultry manure at two application rates (168kg-N/ha and 336 kg-N/ha) on a corn- soybean rotation system. Commercial fertilizer UAN was also studied at the rate of 168 kg-N/ha to compare the differences in effects between poultry manure and UAN fertilizer. This eight year study resulted in the following conclusions:

1. Poultry manure application significantly increased corn and soybean yield in comparison with the UAN application. An increase in corn yield was observed for both poultry manure treatments over an eight year period in the order of PM2>PM>UAN>None. The double N application rate in PM2 treatment gave significantly higher corn yield than those of PM and UAN treatments. However, the difference in corn yield from PM treatment and UAN treatment was not significant. Although soybean did not receive fertilizer in this experiment, there was also a significant increase in soybeans yield on manure treated plots compared to two other treatments. Therefore, long-term use of poultry manure has shown to boost more crop yield in comparison with the UAN application.

2. Nitrogen uptake by corn was found to be higher in poultry manure treatments, especially under high application rates of 336 kg-N/ha. There was a significant difference in crop N uptake between PM and UAN treatments.
3. Even though there were high fluctuations in rainfall rates and the seasonal effects at the experimental site, the volume of tile flow resulted in the highest in the control treatment and second highest in the UAN treatments. The PM treatment resulted in least losses of NO_3-N and PO_4-P with subsurface drain water in comparison with the PM2 and UAN treatments. The average flow weighted of NO_3-N concentration in tile drain was observed to be higher than the EPA drinking water standard of 10 mg/L in all treatments.
4. Poultry manure showed the potential of improving chemical and biological properties of soil over long-term application. Soil pH value in the top soil layers (0-15 cm) receiving poultry manure over eight years was increased in comparison with the UAN treatment.
5. Long-term application of poultry manure had a significant impact on residual soil NO_3-N and PO_4-P concentration, especially in the top soil layers. The residual NO_3-N and PO_4-P concentrations on top soil residue were higher in PM2 and PM treatment in comparison with the UAN treatment. However, there was a risk of P built up in top soil layers over long-term application in PM2 treatment because of excessive P from N-based application rates.
6. The crop rotation has a strong effect on temporal variability in residual soil NO_3- N and PO_4-P concentrations in top soil layers (0-15 cm and 15-30 cm) under all treatments.

In conclusion, the results from the long-term study indicated positive effects on crop yields, crop N uptake, subsurface drainage water quality, and soil nutrient status and the optimum application of poultry manure at a rate of 168 kg-N/ha under a corn-soybean rotation system in Iowa. Therefore, on the basis of overall results of this study, application of poultry manure at the rate of 168 kg-N/ha is recommended for corn and soybean production in Iowa for reducing the negative impacts of using manure on environmental quality while still maintaining higher crop yields and saving money for not using commercial N, P and K fertilizer.

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