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Impacts of long-term application of poultry manure on subsurface drain water quality

by

Nguyen Quang Huy

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Environmental Science

Program of Study Committee:
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ABSTRACT

With a steady growth of egg industry in Iowa as the leading state in the US, there is a huge amount of poultry manure released into the environment and need to be treated properly. Land application of poultry manure on crop production and pasture has been considered as proper management practice to utilize the valuable nutrient content of poultry manure (N, P, K and other minerals) for crop development instead of chemical fertilizer. However, there is an environmental risk of over-applying poultry manure on soil and water quality especially for field plots having tile-drained systems. A few long-term studies have been done to evaluate the impacts of poultry manure application rates on soil and subsurface water quality, and crop production to expose the experiment over a wide range of weather conditions for better understanding and being able to provide informed recommendations. A long-term study (1998-2009) was conducted to evaluate the environmental impacts of surface applied poultry manure on crop production, nitrate and phosphorus leaching in tile drain water as well as nitrate and phosphorus built-up in top soil. Application rates include two poultry manure application rates (168kg-N/ha - PM and 336 kg-N/ha – PM2) with three replications for each rate, urea ammonium nitrate – UAN (168kg-N/ha) with four replications and a control - None (0kg-N/ha). These treatments are assigned on eleven field plots equipped by a state-of-the-art single subsurface tile drain. Tile drain is intercepted by a sump to collect the tile flow and sample water. Corn is planted on one half and soybean on the other half of the plot. Only corn areas receive the treatments. Corn and soybean are rotated yearly. Soil NO_3-N and PO_4-P concentration are collected in Spring (before applying manure) and Fall (after harvesting) at the depth of 120 cm from the surface, then divided into 5 depths (0-15, 15-30, 30-60, 60-90, 90-120 cm). The long-term trends showed the increase of crop yield when applying poultry manure in compared with other treatments (UAN and None). However, PM2 treatment yields much higher NO_3-N and PO_4-P concentration residual in soil profile, especially on the top soil (0-30cm) than those of PM treatment. Seasonal effects of soil nutrient were significantly at the top soil (0-30cm) for PO_4-P in all treatments in which PM and PM2 had a tendency to increase PO_4-P concentration at post harvesting while UAN and None showed somewhat declining trends over 12 years. In addition, PM treatment gives the lowest tile flow, NO_3-N, PO_4-P concentration and losses in tile drain water lower than those of PM2 and UAN treatments on both yearly and monthly average. Seasonal effects of wet-dry-normal weather cycle also showed that the carried over of NO_3-N concentrations were lower with PM treatments than those of PM2 and UAN treatment. These findings are significant in term of reducing nutrient losses in subsurface drainage at the early stage of corn development. Thus, poultry manure at low rate (168kg-N/ha) appears to be suitable for corn-soybean rotation production with tile-drainage in Iowa.

CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

Since 2001, Iowa has led the nation in the production of corn, soybeans, pork and eggs (USDA-NASS, 2010). Currently, with over 92,600 farms covering 30.8 million acres, Iowa raised more than 2.4 billion bushels of corn or 18 percent of the total U.S. corn crop of 13.2 billion bushels, and more than 486 million bushels of soybeans in 2009 or 14 percent of the nation's 3.36 billion bushels in 2009 (Iowa Agricultural Statistics, 2010). Besides, the Iowa's egg producers had 53.8 million layers producing 14.47 billion eggs in 2009. Along with that fast growing of egg industry, approximately 651,000 Mg of poultry manure released to the environment and imposed a thread for surface and ground water quality if not treated appropriately (Iowa Agricultural Statistics, 2010). With the increase of cost for commercial N fertilizer, the utilization of poultry manure as input of crop production in Iowa is likely an economical and environmental sound management practice (Sawyer et al., 2002). The potential for contamination of ground and surface waters 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 (Edwards and Daniel, 1992; Moore et al., 1995). The nutrient content in poultry manure is higher that of than other types of manure (Nahm, 2003). Table 1 presents the main nutrient contents (N-P-K) from five main types of poultry manure in Iowa. The results show that there is an imbalance of N:P ratio which in turn could cause excessive of P input for crop usage if poultry manure is used as fertilizer in comparision with chemical N fertilizer (Angel and Power, 2006; Sawyer et al., 2002). The release of N and P from poultry manure is different from that of chemical N fertilizer (Robinson and Sharpley, 1995; Shepherd, 1993) and may require a suitable BMP when poultry manure is applied in crop production to avoid nutrient losses in surface run-off and leaching via subsurface drainage water (Adams et al., 1994; Adraski et al., 2000; Chambers et al., 2000).

Table 1.1 Estimated average of nutrient content from different poultry manure types in Iowa

Poultry manure types	Liquid manure			Solid manure		
	Total N	Total P (as P_2O_5)	Total K (as K_2O)	Total N	Total P (as P_2O_5)	Total K (as K_2O)
Broiler	63	40	29	46	53	36
Pullet	60	35	30	48	35	27
Layer	57	52	33	34	51	26
Turkey	53	40	29	40	50	30
Duck	22	15	8	17	21	30

(Adapted from Midwest Plan Service (MWPS) Bulletin Manure Characteristics, MWPS-18 Section 1.)

The subsurface drainage systems have significantly contributed to converting prairies and marshlands to productive agricultural lands in the Midwestern U.S. (Zucker and Brown, 1998; Dinnes et al., 2002). In Iowa, approximately 3.6 million ha of row crop area benefits from subsurface drainage during the growing season from April to October in Iowa thanks for its removal of excess water from the soil profile, and thereby providing a suitable environment for crop production (Baker et al., 2004, Cambardella, 1999; Baker and Johnson, 1981). Land application of manure in crop production may cause adverse impacts on environmental quality of soil, water quality if applied more than the rates required by crops, especially for field having subsurface drainage systems (Kingery et al., 1994; Edwards et al., 1995; Blackmer et al., 1997; Delaune et al., 2004; Harmel et al., 2004).

Many studies have documented the increase of NO_3-N and Po_4-P in surface run-off and subsurface water quality from poultry manure treated plots and lysimeters, especially after heavy rainfall events or under artificial irrigation (Bergstrom and Kirchmann, 1999; Bekele et al., 2006; De Vos et al., 2000; Adams et al., 1994; Harmel et al., 2009).

The short-term studies on impacts of poultry manure on water quality may not account for variable weather conditions over extended periods, especially when the experiments are under drought or wet period (Orecroft et al., 2000; Randal and Mulla, 2001; Kladivko et al., 2004). By continuing the treatments over a long period, it may help to assess the effects of poultry manure on soil P and N built up on top soil as well as the behavior of drainage systems under wide variety of climatic inputs. Thus, long-term studies can help to have a better evaluation and understanding of the impacts of poultry manure application on crop yield (Hirzel et al., 2007; Izaurrallde et al., 1995), subsurface water quality (Randal et al., 1995); nitrate and phosphorus dynamic in soil profile (Kratz et al.,, 2004) to provide appropriate recommendations for poultry manure management practice (Kladivko et al., 2004). 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) (Basso et al., 2005; Chinkuyu and Kanwar, 2000; Moore and Edwards, 2007; Mitchell and Tu, 2005; McDowell and Sharpley, 2004).

Not much information about the long-term effects of poultry manure on corn-soybean rotation in which corn and soybean are planted in the same year and rotated yearly on field equipped a subsurface drainage system in Iowa. Therefore, a field study of the impacts of long-term land applied poultry manure on crop yield, subsurface water quality and soil nutrient was initiated in 1998 to provide a better understand of poultry manure utilization on corn and soybean production. Data from this study aims to fill the critical gaps in knowledge of poultry manure over long-term surface application on crop production in Iowa and Midwestern agronomic and climatic systems. It also benefits for growers to make more informed decisions on a suitable Best Management Practice when poultry manure is used as fertilizer for corn production.

1.1.1 Research Hypotheses

1. Long-term land applied poultry manure may increase the PO_4-P and NO_3-N level residual in soil profile and consequently may result potentially high PO_4-P and NO_3-N losses via leaching into tile drain water.
2. Excess poultry manure application rates than crop requirement may result in higher PO_4-P and NO_3-N residuals in top soil (0-30cm), increase in PO_4-P and NO_3-N concentrations and losses in tile drain water, and crop yield.

1.1.2 Research Objectives

1. To quantify the effects of poultry manure application rates on crop yield, N uptake, NO_3-N and phosphorus leaching in tile drain water, and PO_4-P and NO_3-N residuals in the soil profile.

2. To compare the effects of poultry manure with UAN on crop yield, N uptake, nitrate and phosphorus leaching in tile drain water; and soil PO_4-P and NO_3-N residual over long-term application.
3. To evaluate the trends in crop yield, nitrate and phosphorus leaching in tile drain water, soil PO_4-P and NO_3-N dynamic over years; and the build-up of PO_4-P and NO_3-N in top soil (0-30cm) over long-term applied poultry manure.

1.2 Research Project Overview

The project was first publicly funded in Iowa to study of environmental impacts of the use of poultry manure on water quality initiated in 1998 by the Iowa Egg Council and the Leopold Center for Sustainable Agriculture. Phase 1 of the project (1998-2000) was conducted using six field lysimeters and nine plots located at the Agronomy and Agricultural Engineering Research Center near Ames, Iowa. Lysimeters and field plots were fully instrumented, each with a single subsurface drain and sump to collect subsurface drain water samples for water quality analyses (Kanwar et al., 1999; Chinkuyu et al., 2000). Two field plots were outfitted with H-flumes to collect surface water samples for water quality analyses. Poultry manure was applied to plots and lysimeters to give N application rates of 168 and 336 kg-N/ha to corn under corn-soybean rotation. For comparison purposes, UAN fertilizer was applied to four plots at an N application rate of168 kg-N/ha. In December 1999, one more sump was installed to intercept a tile line from the ninth plot, which had not received any manure for the past five years. This plot was sampled for subsurface drain water quality in 2000. Data on NO_3-N, PO_4-P, and bacteria concentrations were collected for water samples from drains and H-flumes in 1998, 1999, and 2000 to observe the effects of poultry manure application on water quality (Chinkuyu et al., 2002). Phase 2 (2001-2003) continued monitoring of the run-off and subsurface drainage water quality in both field plots and lysimeters (Cheatham et al., 2004). The data for the first six years (1998-2003) was presented in Cheatham et al. (2004). Phase 3 (2004-2009) was focused on evaluating the long-term effects of poultry manure on nitrate and phosphorus leaching in tile drain water, trends in crop yield, and residual soil nitrate and phosphorus build-up in the top soil. Data on surface run-off and pathogen were not collected during this phase. Only data related to subsurface drainage water quality from nine field plots were collected and analyzed.

1.3 Dissertation Overview

This dissertation is organized as a combination of three separate papers to be submitted to peer-reviewed journals for publication. Chapter 1 is a general introduction of poultry industry, corn and soybean production in Iowa as well as the environmental impacts of applying poultry manure on soil, water quality and crop production. Chapter 2 is a paper entitled “Long-term effects of repeated surface land applied poultry manure on nitrate leaching in subsurface drainage” in which the trends in tile flow and nitrate leaching in tile drain water in response to different application rates and types of fertilizer are investigated. Chapter 3 contains a paper on the “Long-term effects of poultry manure on crop yield, N uptake and soil nitrate residual from corn-soybean production” in which the effects of N application rates and sources of N on trend of crop yield and N uptake by corn; trend of soil nitrate residual in soil profile (0 – 120 cm) are evaluated. Chapter 4 is a paper entitled “Phosphorus transport in soil and tile drain water under long-term application of poultry manure” in which the dynamic of P released from surface applied poultry manure is investigated. Chapter 5 summarizes the general conclusions and recommendations for future studies.

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CHAPTER 2. LONG-TERM EFFECTS OF REPEATED SURFACE APPLIED POULTRY MANURE ON NITRATE LEACHING IN TILE DRAINAGE WATER

by Huy Nguyen, Ramesh Kanwar, Philip Dixon, Jon Hobbs and Carl Pederson

(A paper to be submitted to Transactions of the ASABE)

2.1 Abstract

Repeated surface applied poultry manure on field plot having subsurface drainage system may cause environmental concerns on water quality. A long-term study was initiated since 1998 to investigate the effects of poultry manure application rates on subsurface drainage water quality in Iowa under a corn-soybean rotation system. Corn is grown in one half of the plot and soybean is grown in the other half. Corn and soybean are rotated yearly but only the corn area receives fertilizer (poultry manure or chemical fertilizer). Treatments including two poultry manure application rates (168kg-N/ha -PM and 336 kg-N/ha – PM2) with 3 replications; chemical fertilizer urea ammonium nitrate – UAN (168 kg-N/ha) with 4 replications and a control (0 kg-N/ha - None) are assigned into eleven field plots under unbalanced randomized design. Data on tile flow volume and NO_3-N concentration in subsurface drainage are collected weekly. The results of twelve years study (1998-2009) show that nitrate losses in tile drain water are more likely occurred during the early stage of crop production (April-Jun) and more related to the monthly distribution of precipitation than the total rainfall amount. Overall, the PM treatment gives significantly lower tile flow volume (PM<UAN<PM2<None), flow weighted nitrate concentration (PM<UAN<PM2),

and nitrate losses (PM<UAN<PM2) in tile drain water both at monthly and yearly average in comparison to other treatments. It is suggested that applying poultry manure at the rates close to 168kg-N/ha may reduce nutrient losses in tile drain water and avoid advert impacts on subsurface drainage water quality.

Keywords: Poultry manure, nitrate leaching, corn-soybean rotation, repeated measures, subsurface drainage.

Abbreviations: PM, poultry manure application rate with 168 kg-N/ha; PM2, poultry manure application rate with 336kg-N/ha; UAN, Urea Ammonium Nitrate.

2.2 Introduction

During the last 10 years, Iowa has been leading the nation in corn/soybean production as well as egg production (NASS-USDA, 2009). The fast and steady growths of these industries have imposed challenges for proper treatments of huge amount of poultry manure released into the environment (estimated at approximately 6.5 million Mg poultry manure in 2009) and increased demands for N fertilizer input for crop growers. Thus, land application of poultry manure is likely an environmental and economical sound solution for the above issues in Iowa and other regions in the US having concentrated growth of the poultry industry as well (Edwards and Daniel, 1992; Moore et al., 1995; and Sharpley et al., 1998 and Shepherd, 1993). Poultry manure is agronomical considered as valuable fertilizer as a great source of N-P-K and other micro-nutrients (Mg, Zn, Cu, etc.) for crop production. The environmental issues associated with utilization of poultry manure are often over application than the recommendation rates for crop's need due to limited land available and increased cost of transportation. In Iowa and several other states in Corn Belt Region of the US, the surface land application of poultry manure also associated with nitrate leaching via subsurface drainage systems under crop fields (Dinnes et al., 2002; Baker and Johnson, 1981; Bakhsh et al., 2002). Up to date, nearly 50% of agricultural farm land in Iowa is equipped with artificial subsurface drainage or “tile drain” to help reduce the water table below the root zone for crop production (corn, soybean) (Baker et al., 2005; Weed and Kanwar, 1996). Many studies documented the transport of nutrient (nitrate and phosphorus) and pathogens leaching from agricultural land via tile drainage to impair the surface water quality of lakes, streams and rivers. Nitrate loss in tile drain water was found highest in early Spring when crop is not yet developed and decreased sharply during the crop season due to the reduce of tile drainage and N crop uptake (Rossi et al. 1991; Sharpley and Syers, 1979).To reduce the NO_3-N leaching effectively, many studies suggested that the long-term N application rates should closely match the crop requirements (Andraski et al., 2000; Ersahin, 2001; Dinnes et al. 2002). Adams et al. (1994) investigated the effects of different poultry manure application rates for fescue plots on nitrate concentration in groundwater. Wood et al. (1996) also found the increase of nitrate leaching in tile drain from corn plots having long-term applied poultry manure. Quantification of drainage and nitrate leaching from cropping systems having applied poultry manure is needed to optimize poultry manure value and establish an informed management practice as well as to determine the impacts of poultry manure application on water quality in Iowa. Field subsurface drainage water quality data are limited, especially for long-term (>10 years) studies on impacts of land application of poultry manure on nitrate leaching from a corn-soybean rotation in which corn and soybean are planted in the same year and rotated yearly on field having subsurface drainage system in Iowa. Therefore, a field study of the impacts of long-term land applied poultry manure on crop yield, subsurface water quality and soil nutrient was initiated to provide a better understand of poultry manure utilization on corn and soybean production.

The hypotheses of the study are (1) applying poultry manure at the same rate of N chemical fertilizer may yield equal or less nitrate concentration and losses in tile drain water due to slow N released from poultry manure in comparison with UAN; and (2) increase the application rates of poultry manure over the amount crop needed may increase nitrate loss in subsurface drainage water. The specific objectives of this study are (1) to evaluate the effects of different fertilizer application rates (poultry manure and UAN) on tile drainage flow, NO_3-N concentration and losses over years; and (2) to compare changes in trends of nitrate losses in tile drain water as responses to different N treatment inputs. The implications of the study may contribute to establish recommended practices for poultry manure application on corn and soybean production as well as to promote a sustainable eco-agricultural system and poultry/egg industry in Iowa.

2.3 Materials and Methods

2.3.1 Experimental site description

Field experiments were conducted from 1998 to 2009 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 table (Chinkuyu et al., 2002). Eleven field plots (with sizes varied from 0.19 ha to 0.47 ha) having the 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. 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) was planted on the other half of the same plot followed by the same procedure of crop rotation from the previous years (1998-2009). Fertilizer was applied only on corn side of each field plot. Poultry manure fertilizer at two different rates (168kg-N/ha and 336kg-N/ha) and a liquid 28% Urea Ammonium Nitrate (UAN) at a rate of 168kg-N/ha 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 0 kg-N/ha on the year of 2000 for comparison purposes. Corn and soybean residuals are left on the field using moldboard tillage which maintains at least 30% of crop residuals remained on the field. The detailed schedule of agronomic activities on Field 5 is presented on Table 2.1. More details of field activities are found in previous work of Cheatham et al. (2003) and Chinkuyu et al. (2002) at the same research site.

2.3.2 Sample collection and analysis

Three poultry manure samples were collected and sent to laboratory in Nevada, IA for analyzing the contents of N, P and K in order to determine the actual poultry manure application rates. The summary of poultry manure characteristics applied on field plots is presented in Table 3. Two water samples were collected weekly and/or after rainfall events (> 5 cm) on each field plot. After that, these samples were transferred to the Water Quality

Laboratory of the Agricultural and Biosystems Engineering Department at Iowa State University for analyzing NO_3-N with reduced cadmium methods using a Lachat Model AE ion analyzer (Lachat Instrument, Milwaukee, WI).

2.3.3 Experimental design and statistical data analysis

Eleven field plots were used in this experiment with corn grown in one half of the plot and soybean grown on the other side. Rotation was done yearly for 12 years (1998-2009). Four fertilizer treatments including poultry manure (168kg-N/ha and 336 kg-N/ha), UAN (168kg-N/ha) and a control treatment (0 kg-N/ha) were applied on the field plots (only on corn side). All the treatments were arranged in a completely randomized design with unbalance replications due to the lack of land for experiment.

Data from 12 years (1998-2009) of rainfall, tile flow, nitrate concentration and losses in tile drain waters were analyzed collectively with months within year as repeated measures (Kaspar et al., 2007; Bakhsh et al., 2010). The MIXED procedure (Littell et al., 1996) of SAS (SAS Institute, 2009) was used in which source of fertilizers, year, rainfall are treated as fixed effects and the plot is considered as random effect. The appropriate covariance structure is selected for tile flow, nitrate concentration and losses based on minimum values of AIC for the covariance among observations across years within a plot. Details of selection process to choose covariance structure for repeated measures analysis are presented in Littell et al. (2006) and Piepho et al. (2004). Least square means of the fixed effects were computed, and the PDIFF option of the LSMEANS statement was used to display the differences among least square means for comparison. The LSMEAN values were used to compare treatment means and evaluate the treatment effects on tile flow, flow weighted nitrate concentration and nitrate losses in tile drains. In all of the statistical analysis, a significant level $\alpha = 0.05$ was used to evaluate the significant differences of hypothetical testing.

Tile flow: The model for the square root of subsurface flow include treatment-specific cubic polynomials for the year, treatment-specific month effects (constant across years), a coefficient for monthly rainfall, and random effects for plots, months within years. Repeated measures covariance structures were examined for observations on the same plot in the same year. A compound symmetry structure gave the minimum AIC.

The mathematical model for tile flow:

$$Y_{ijk\ell} = \sqrt{\text{Tile flow (cm)}} \text{ for treatment } i, \text{ year } j, \text{ plot } k, \text{ month } \ell$$

or $Y_{ijk\ell} = \beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3 + \beta_4 x_{2j\ell} + \tau_{i\ell} + \alpha_{ik} + \gamma_{j\ell} + \varepsilon_{ijk\ell}$

where:

$x_{1j} = \text{Year - 2003.5}$: Cyear

$x_{2j\ell} = \text{Precipitation (cm)}$: Monthly rainfall

$\alpha_{ik} \sim N(0, \sigma_\alpha^2)$: Plot effect

$\gamma_{j\ell} \sim N(0, \sigma_\gamma^2)$: Month within year

$\tau_{i\ell}$: Treatment effects at specific month

$\beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3$: Long-term trend

$\alpha_{ik} + \gamma_{j\ell} + \varepsilon_{ijk\ell}$: Random effects

NO_3-N concentration: The model for the natural logarithm of monthly NO_3-N concentration includes treatment-specific cubic polynomials for the year, treatment-specific month effects (constant across years), a coefficient for monthly rainfall, and random effects for plots, months within years. Repeated measures covariance structures were examined for observations on the same plot in the same year. A compound symmetry structure gave the minimum AIC.

$$Y_{ijk\ell} = \log \text{NO}_3\text{-N concentration} \quad \text{for treatment } i, \text{year } j, \text{plot } k, \text{month } \ell$$

$$Y_{ijk\ell} = \beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3 + \beta_4 x_{2j\ell} + \tau_{i\ell} + \alpha_{ik} + \gamma_{j\ell} + \varepsilon_{ijk\ell}$$

where:

x_{1j} = Year - 2003.5 : Cyear

$x_{2j\ell}$ = Precipitation (cm) : Monthly rainfall

$\alpha_{ik} \sim N(0, \sigma_\alpha^2)$: plot effect

$\gamma_{j\ell} \sim N(0, \sigma_\gamma^2)$: month within year

$\tau_{i\ell}$: treatment effects at specific month

$\beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3$: long-term trend

$\alpha_{ik} + \gamma_{j\ell} + \varepsilon_{ijk\ell}$: random effects

Total annual NO_3-N loss: The model for the natural logarithm annual total NO_3-N loss includes treatment-specific cubic polynomials in time, a coefficient for rainfall, and random effects for year and plot.

$$Y_{ijk} = \log \text{NO}_3\text{-N } loss \quad \text{for treatment } i, \text{year } j, \text{plot } k$$

$$Y_{ijk} = \beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3 + \beta_4 x_{2j} + \alpha_{ik} + \gamma_j + \varepsilon_{ijk}$$

where:

x_{1j} = Year - 2003.5 : Cyear

x_{2j} = Precipitation (cm) : Total annual rainfall

$\alpha_{ik} \sim N(0, \sigma_\alpha^2)$: Plot effects

$\gamma_j \sim N(0, \sigma_\gamma^2)$: Year effect

$\varepsilon_{ijk} \sim N(0, \sigma_\varepsilon^2)$: Error

$\beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3$: Long-term trend

2.4 Results and Discussions

2.4.1 Poultry manure characteristics and application rates over years (1998-2009)

The characteristics of applied poultry manure on field experiments are presented in Table 2.2. Poultry manure analyses showed that its nutrient and solid matter contents were highly variable throughout the study period. Based on these analyses, the calculated N application rates were made for poultry manure treatments every year as in Table 2.3. The analysis of poultry manure over year revealed that to achieve the right target application rates may be difficult but it seems to be comparable in the range close to the 168 kg-N/ha target rate. The moisture content of poultry manure in this study ranged from 25 to 76% which may cause the high variability of N and P percentage in poultry manure over year. Thus, the following comparison will be made on N application rates rather than total poultry manure amount alone.

On average, the actual N application rates on PM and PM2 treatment are 179 kg-N/ha and 336 kg-N/ha respectively. The application rate was low in year 2000 because we were allowing a 10% carryover N credit from manure application in 1998. An N credit from each kg of soybean yield was in full 100% to the following year at that time. The true targets of 168 kg-N/ha and 336 kg-N/ha are actually obtained when the calculated credits are applied to each plot with the actual N applications. These calculations were based on early calculations when we were unsure of carryover and credit assumptions. After year of 2000, we stopped doing N credit from soybean to following year in poultry manure application rates' calculation. Besides, from the average of actual N and P application rates, it showed that the N: P ratio is not balance from year to year and between PM and PM2 treatments. That may be a cause to fasten P built-up or leaching if the amount exceeded crop's need. Generally, the recommended rate of N for corn production in Iowa is in the range closed to 168 kg-N/ha (Blackmer et al.,1997; Sawyer et al., 2002); however, if poultry manure is in used, it may need further validation from long-term studies for better understanding and evaluation of the impacts of poultry manure application rates on water quality (Leclerc et al., 1995; Chinkuyu et al., 2002; Dinnes et al., 2002; Jaynes and Colvin, 2006). One of the reasons is that the amount of N released from poultry manure is different from that of chemical fertilizers, and not all N amounts is available after poultry manure applied (Robinson and Sharpley, 1995). Normally, only 40-60 percent of N amount in poultry manure is available for crop use after first year applied, the rest is slowly mineralized or transformed in soil in the following years (Cabrera et al.,1993; Cooperband et al., 2002).

2.4.2 Research site precipitation and the effects of precipitation on subsurface drainage

The precipitation data was collected daily from an automated weather station (Iowa State University Agriculture Engineering Farm, Iowa Environment Mesonet) at research site and was summarized in monthly data from March to October as in Table 2.4. The long-term 30 years normal precipitation for Ames, Iowa (1961-1990) was 740 mm from March to October. During 12 years of study from 1998 to 2009, the average precipitation at the experimental site was 798 mm or 8% above the long-term normal trend for this site. Four years of 1999, 2007, 2008, and 2009 were wetter than the normal precipitation amounts with the precipitation of 949, 915, 1145 and 829 mm, respectively. The year of 2000 (437 mm) was drier than the normal amounts. Seven years out of 12 years had the precipitation within 10% of the normal. High precipitation in 1999 following a dry year of 2000 and a normal year of 2001 made a significant weather cycle that affected the tile flow and nitrate losses in tile drain water. Analysis of monthly average precipitation revealed that April, May and August precipitation are higher than the normal trend (Fig. 2.1). The early peaks and increasing amount of rainfall in April and May than normal gave potential of increasing tile flow volume and eventually nitrate losses in tile drain water; thus, requires further agronomical management practice attention (Randal and Iragavarapu, 1995; Randall and Vetsch, 2005).

The subsurface drainage volume or tile flow from field plots was normalized and transformed for statistical comparison purposes among treatment effects. As expected, the variation of precipitation patterns considerably affected the variation of tile flow volumes at both yearly and monthly levels (Table 2.5). Figure 2.2 presents the effects of precipitation on tile flow from all treatments over years. Tile flows were lowest in year of 2000 as a drought year and highest in year of 2008 as wettest year. The trends of tile flow appeared to proportional with the increasing or decreasing of precipitation over year. Overall, the PM treatment (168 kg-N/ha) had the lowest tile flow (9.9 cm/year) in comparison to others in all years ($p<0.001$). The control treatment (0 kg-N/ha) yielded the highest tile flow (13.3 cm/year), maybe due to the fact that having less cropping development to consume the rainfall and/or less root development systems from crop to retain the water than other treatments. Average of tile flows from PM2 and UAN treatments were not significantly different from each other ($p=0.057$). At monthly levels, statistical analysis showed that seasonal distribution of rainfall over year had significant impacts on tile flow rather than the total yearly rainfall amount ($p=0.013$) (Table 2.6). Also, high variability of tile flow from plot to plot at monthly level are observed in this site ($p=0.002$) from all N treatments. The tile flows in this study had general trend of increasing from April to June and leveling off after July or August since crop may consume most of precipitation for growing after July. Similar spatial variable of tile flow are also found in several other studies because the changes of soil characteristics after long-term cultivation with different N regimes and crop productions (Hansen et al., 1996; Bakhsh et al., 2010; Adams et al., 1994; Bjorneberg et al., 1998). For example, Kladivko et al. (2004) found that there was no difference from trends in tile flow between corn year and soybean during 6 years study because each year had a different combination of rainfall timing, intensity, and amount.

Timing of precipitation showed a great impact on subsurface drainage volume and the timing of NO_3-N export in tile drain water in rain-fed experiments, especially with the cycle of wet-dry-normal weather condition in Mid-west areas. Several studies of nitrate leaching in Midwest region reported that variation NO_3-N concentration and losses may not much associated with daily flow but mostly with seasonal variation of tile flow (Kanwar et al., 2005; Lawlor et al., 2008; Jaynes et al., 2001; Bakhsh et al., 2007; Mitsch et al., 2001; Dinnes et al., 2002 and Randall and Mulla, 2001). Bakhsh et al., (2010) found that precipitation pattern during the growing season of crop production was the main factor of NO_3-N export with higher tile flow volumes in early stage of crop growth under swine manure experiments in Nashua, Iowa. Bjornerberg et al. (1996) reported the seasonal effects on tile flow in subsurface drainage system with higher flow occurred before fertilizer application.

2.4.3 Effects of N fertilizers on tile drainage flow

Data of monthly tile flow volumes from all field plots are normalized for better statistical comparison. Not all months during a year that the flow occurs and highly varies from plot to plot. The effects of N treatments (poultry manure or UAN) on tile flows over years with effects of annual total precipitation are presented in Figure 2.2. Yearly average of tile flows under different N treatments: PM2, PM, UAN and None are 12.3, 9.9, 13.3, 25.6 cm, respectively. In all years, PM treatment significantly gives the lower tile flow in comparison to others under different weather cycles (wet, dry and normal) and conditions (Table 2.7). When applying poultry manure at double rates (PM2), the tile flow is still lower than those of chemical fertilizer (UAN) or control (None). Thus, it may be significant to consider poultry manure for corn-soybean rotation production since tile flow and nitrate losses are linearly correlated as found in many other studies. (Randal, 1998; Rossi, 1991; Shepherd, 1993; Simmelsgaard et al., 1998; Smith et al., 2003 and Kanwar et al., 2005). Kirchmann et al. (2002) suggested that reducing tile flow volume may possibly reduce the amount of nitrate export from agriculutre land. Bjornerberg et al. (1996) found a strong linear relationship of nitrate losses with the changes of tile flow during crop growing season under different tillage systems (chisel plow, modlboard plow, ridge till and no-till). Durry et al. (1993), Randall and Mulla (2001), and Kanwar et al. (2005) reported that applying extensive crop rotations rather than mono-crop production and conservational tillage system may also help to leveling off the subsurface drainage volume in agriculutre management. However, the scope of this study is focused on impacts of poultry manure application rates on subsurface drainage water quality. Future studies may explore further these possible combination effects of tillage, crop rotation and poultry manure rates on water quality. The effects of N treatments on tile flow at monthly level as response of different N treatments under wet, dry and normal weather cycles will be discussed later on.

2.4.4 Effects of N fertilizers on nitrate concentration in tile drain waters

Average monthly flow weighted nitrate concentrations from tile drain water from 1998 to 2009 are presented in Table 2.8. Yearly average of flow weighted NO_3-N concentration as effects of N treatments over times is presented in Figure 2.3. The PM treatment significantly yields lower NO_3-N concentration in tile drain water ($p<0.01$) ranging from 9.5 mg/L in 2009 to 23.2 mg/L in 2004 with an average of 15.2 mg/L after 12 year study. In contrast, PM2 treatment gives highest NO_3-N concentration overall ($p<0.01$) (ranging from 10.4 mg/L to 37.8 mg/L with an average of 22.4 mg/L). Statistical analysis shows that the effects of treatment and monthly distribution of rainfall and tile flow significantly impact on NO_3-N concentration in tile drain water (Table 2.6). The monthly analysis also show that not all months having the tile flow. For example, flow occurred in March only in the year 1998 and in October in the year of 2006 while months from April to July have most of the flow in all years. Also, the effects of the dry year (2000) increased the NO_3-N concentration in the following years (2001 and 2002) as shown in the months of April, May and June (Table 2.8). Average flow weighted NO_3-N concentration from all years are negatively related to tile flow (Figure 2.4) as expected.

Figure 2.5 presents the trend of average flow weighted NO_3-N concentration from March to October across twelve years (1998-2009) to show the interaction N treatments and month effects (tile flow and rainfall). The trends of NO_3-N concentration increase sharply in month of June, normally due to poultry manure applied in May (Table 2.1) and increase of rainfall in June and decrease after July (Figure 2.1). Overall, the PM treatment also shows to have lower NO_3-N concentration in comparison to those of UAN and PM2 treatments.

Small tile flow in May or June after applied poultry manure may result stiff increase of NO_3-N concentration in tile flow. Therefore, the further investigation of long-term trends of NO_3-N concentration at monthly level are focused on months of May, June and as presented in Figures 2.6 and Figure 2.7 over years from 1998 to 2009. Even there is a highly variable of NO_3-N concentration among the treatments over years, it shows that after 8 years of the study, the systems seem to be stable with the trend of NO_3-N concentration are leveling off in both months of May and June. This also emphasized the needs of long-term study on future poultry manure research to examine the effects of treatments under a wide range of weather conditions and patterns for better understanding of nitrate leaching from poultry manure to tile drain water.

In short, it is concluded that applying poultry manure at lower rate (168 kg-N/ha) possibly gives lower NO_3-N concentration in tile drainage water than those of double rate poultry manure (336 kg-N/ha) and chemical fertilizer (168 kg-N/ha) at monthly level during crop growing season.

2.4.5 Seasonal effects of precipitation and poultry manure application rates on nitrate losses in tile drain waters

Since nitrate losses, tile flow volume and nitrate concentration in tile drain water are all related, the trends of monthly nitrate losses as response to different N treatments over time are presented as accumulated nitrate losses over years (Figure 2.8). On average, the PM2 and UAN treatment gives nearly twice nitrate losses in comparison to that of PM treatment starting in month of April till the end of September. The twelve years' average NO_3-N losses of PM2, PM, UAN and None treatments are 25.7, 14.7, 23.6, and 19.0 kg/ha respectively. Figure 2.9 shows the relationship of nitrate concentration in subsurface water and N application rates. Linear correlations of nitrate losses with tile flow water from field plots are observed (Figure 2.10). Total rainfall shows significant effect on total annual nitrate losses in tile drain water (Table 2.9). With a wide range of N application rates from poultry manure in this study (from 87 kg-N/ha to 301 kg-N/ha with an average of 179 kg-N/ha), it is noticeable that PM treatment still yields lower nitrate losses than UAN treatment at the exact application rate of 168kg-N/ha. Many studies on impacts of chemical N fertilizer on nitrate leaching in subsurface drainage water showed that small changes from in the range of chemical N fertilizer application rates may cause greatly increase of nitrate export in tile drain water (Bergstrom and Kirchmann, 1999; Andraski et al., 2000; Adams et al., 1994; Baker and Johnson, 1981; De Vos et al., 2000; Zhu and Fox, 2003; Harmel et al., 2004).

The temporal effects of monthly rainfall distribution with different N treatments were investigated at yearly level. Figures 2.11-2.16 present the yearly trends of nitrate losses yearly from 1998 to 2009. Although there was a difference in term of amount nitrate losses by treatments from year to year, the trends of monthly nitrate losses is in agreement with the long-term trends as shown in Figure 2.8 in which nitrate losses from all treatments increase from April to Jun and level off after July. However, PM treatment still gives lower nitrate losses overall in comparison to those of PM2 and UAN treatments ($p<0.05$). Also, in the wet years (1999, 2007, 2008, and 2009), yearly analysis on nitrate losses show that the PM treatment gives the lowest nitrate losses among the four treatments due to high volume of tile flow occurred under control treatments. Similar findings on seasonal effects on nitrate losses are found on experiments in Mid-west areas and elsewhere (Bakhsh et al., 2010; Jaynes and Colvin, 2006; Orecroft et al., 2000; Shepherd and Bhogal, 1998; Sharpley and Syers, 1979).

2.5 Conclusions

A long-term study was conducted to investigate the effects of two poultry manure application rates (168 kg-N/ha and 336 kg-N/ha) on subsurface water quality under a corn-soybean rotation system in Iowa. Treatments include poultry manure at 168 kg-N/ha and 336 kg-N/ha with 3 replications, UAN (168 kg-N/ha) with 4 replications and a control (0 kg-N/ha). Eleven field plots having subsurface drainage system are used in this study. In each field plot, corn is planted in one half and soybean on other half. Twelve year data of tile flow volume, NO_3-N concentration in tile drain water are collected and analyzed as unbalanced randomized design with months within year as repeated measures and plots as fixed effects. The objectives of the study are (1)) to evaluate the effects of different fertilizer application rates (poultry manure and UAN) on tile drainage flow, NO_3-N concentration and losses over years; and (2) to compare changes in trends of nitrate losses in tile drain water as responses to different N treatment inputs. The results of long-term study indicated that poultry manure (168 kg-N/ha) gives lower tile flow, nitrate concentration and losses in tile drain water than other treatments (UAN and PM2) both at monthly and yearly levels. With slowly released and less available nutrient for leaching, poultry manure at lower rate (168 kg-N/ha) may help to delay the nitrate losses in tile drain water in comparison to chemical fertilizer but not at double rate (336 kg-N/ha). Long-term trends of nitrate leaching from all treatment revealed a likely stable state of nitrate concentration under corn-soybean system after 7-8 years study which may be an implication for future study on effects of poultry manure on water quality.

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Table 2.1 Agronomic activities on research field (1998-2009)

Year	**Field activities**					
	Manure application	UAN application	Corn Planting	Soybean Planting	Harvesting corn	Harvesting soybean
	---------------------------Dates-------------------------					
1998	Apr 29	May 1	May 8	May 8	Oct 19	Sep 30
1999	May 4	May 4	May 10	May 10	Oct 14	Oct 12
2000	Apr 13	May 5	May 8	May 8	Sep 20	Oct 4
2001	May 17	May 17	May 18	May 18	Oct 15	Oct 17
2002	May 3	May 3	May 22	May 22	Oct 18	Oct 15
2003	May 16	May 16	--	--	Oct 9	Sep 25
2004	Apr 28	Apr 29	May 3	May 11	Oct 8	Sep 27
2005	May 10	May 10	--	--	Oct 14	Oct 10
2006	May 15	May 15	--	--	Oct 23	Oct 25
2007	May 21	May 21	--	--	Oct 30	Oct 30
2008	May 22	May 22	May 22	May 22	Oct 27	Oct 20
2009	May 12	May 12	May 14	May 14	Oct 12	Sep 30

Table 2.2 Chemical analysis of characteristics of poultry manure applied on field plots

Year	% as TKN	% as Ammonia N	% as K_2O	% as P_2O_5	% H_2O
1998	1.5	1.1	1.3	1.0	47.5
1999	3.0	0.8	2.1	4.3	49.8
2000	3.2	0.8	2.3	3.9	32.4
2001	2.2	1.6	2.0	2.7	57.0
2002	1.6	0.7	0.6	1.1	53.7
2003	1.9	0.9	1.1	1.4	74.6
2004	2.4	1.6	1.1	2.1	69.9
2005	2.1	0.2	3.1	6.1	25.0
2006	2.0	1.0	1.2	2.6	58.4
2007	1.8	1.0	1.4	1.0	76.3
2008	2.2	.	1.1	2.0	59.1
2009	2.7	0.7	1.7	1.9	58.4
Average	2.2	0.9	1.6	2.5	55.2
Std. Error	0.1	0.1	0.4	0.2	0.42

Table 2.3 Annual application rates of poultry manure on field plots (1998-2009)

	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	10632	160	108	153	23163	352	220	300
1999	9866	301	439	230	14953	446	630	278
2000	3254	87	128	79	8872	331	333	199
2001	9013	195	245	181	15318	331	416	308
2002	8063	132	87	49	14468	237	156	88
2003	11565	124	159	123	18636	345	255	198
2004	10364	249	218	117	20006	480	420	226
2005	8871	186	541	278	16725	351	1020	525
2006	9703	195	247	115	17000	342	434	201
2007	9632	171	95	133	19542	346	194	270
2008	8059	164	250	91	15872	324	232	179
2009	6591	180	124	232	13312	363	250	115
Average	8801	179	220	148	16489	354	380	241
Std. Error	633	16	41	20	1057	17	70	32

Table 2.4 Precipitation at research site during the study period (1998-2009)

	Month								Growing Season (May-Sep)	Drainage Season (Mar-Oct)
Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		
					(mm)					
1998	71	81	92	274	68	94	24	102	552	806
1999	25	207	150	185	162	151	61	9	709	949
2000	11	21	120	104	72	34	26	50	356	437
2001	28	96	190	50	48	74	149	65	511	700
2002	10	95	130	81	150	209	38	79	606	790
2003	29	112	122	150	168	25	100	24	565	730
2004	96	61	208	91	50	132	34	45	515	717
2005	35	82	111	124	104	172	111	9	622	748
2006	74	109	55	21	141	156	191	63	564	811
2007	81	153	169	52	75	200	48	137	545	915
2008	71	130	216	271	234	53	78	92	852	1145
2009	103	116	102	104	70	123	24	186	424	829
Average	53	105	139	125	112	119	74	72	568	798
Normal	54	89	108	129	106	102	87	65	532	740

Table 2.5 Average tile flow volume (mm) across all treatments by year and month

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
					(mm)				
1998	2	33	31	96	41	0	0	0	203
1999	0	44	46	55	6	3	0	0	154
2000	0	0	1	4	0	0	0	0	5
2001	0	3	41	22	2	0	0	0	69
2002	0	0	46	19	10	6	0	0	81
2003	0	0	84	10	46	0	0	0	141
2004	15	47	39	52	1	0	0	0	153
2005	0	24	42	10	7	9	0	0	93
2006	0	23	52	3	1	0	72	75	226
2007	0	0	14	59	10	0	0	0	83
2008	0	63	77	167	50	48	0	0	405
2009	0	51	83	27	3	0	0	10	174
Average	1	24	46	44	15	6	6	7	149

Table 2.6 ANOVA table for fixed effects of tile flow, NO_3-N concentrations in tile drain water

Effects	Num df	Den df	F value	Pr > F
Tile flow (mm)	-----------------	-----------------	-----------------	-----------------
Rainfall	1	310	6.27	0.013
Treatment	3	5	2.03	0.228
Cyear	1	310	1.66	0.199
Cyear2	1	310	10.02	0.002
Cyear3	1	310	6.45	0.012
Cyear*Treatment	3	310	1.26	0.287
Cyear2*Treatment	3	310	1.04	0.374
Cyear3*treatment	3	310	0.70	0.555
Month	7	44	2.43	0.034
Month*treatment	21	310	2.17	0.002
NO_3-N concentration (mg/L)	-----------------	-----------------	-----------------	-----------------
Rainfall	1	294	0.86	0.3552
Treatment	3	5	16.51	0.0050
222222222Cyear	1	294	5.3	0.0220
Cyear2	1	294	1.86	0.1735
Cyear3	1	294	1.85	0.1749
Cyear*Treatment	3	294	3.28	0.0214
Cyear2*Treatment	3	294	3.70	0.0122
Cyear3*treatment	3	294	2.02	0.1111
Month	7	38	10.33	<0.0001
Month*treatment	21	294	2.28	0.0021

Table 2.7 Estimates for comparisons of total yearly tile flows, NO_3-N concentrations and losses among the N treatments

Labels	Estimates	Standard Error	df	t value	Pr > |t|
Tile flows					
PM2 vs UAN	-0.098	0.051	81	-1.93	0.0570
PM vs UAN	-0.271	0.051	81	-5.30	<0.0001
PM2 vs PM	0.173	0.046	81	3.73	0.0004
NO_3-N concentration		---------------------------			
PM2 vs UAN	0.158	0.061	81	2.60	0.0112
PM vs UAN	-0.206	0.061	81	-3.39	0.0011
PM2 vs PM	0.364	0.054	81	6.62	<0.0001
NO_3-N losses		----------------------------			
PM2 vs UAN	-0.039	0.103	8	-0.38	0.7059
PM vs UAN	-0.590	0.103	81	-5.72	<0.0001
PM2 vs PM	0.551	0.093	81	5.92	<0.0001

Table 2.8 Seasonal effects on trends of NO_3-N concentrations across N treatments

	Year	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Month	Trt.	----- Flow weighted NO_3-N concentration in tile drain water, mg/L ------											
Mar	PM2	5	-	-	-	-	-	-	-	-	-	-	-
	PM	6	-	-	-	-	-	-	-	-	-	-	-
	UAN	9	-	-	-	-	-	-	-	-	-	-	-
	None	.	-	-	-	-	-	-	-	-	-	-	-
Apr	PM2	18	31	-	10	-	-	27	23	14	-	15	13
	PM	13	19	-	11	-	-	20	17	12	-	11	9
	UAN	17	19	-	6	-	-	30	21	14	-	15	13
	None	.	.	-	4	-	-	4	12	7	-	8	6
May	PM2	17	30	17	43	41	27	12	24	10	13	15	12
	PM	14	25	6	23	21	17	9	19	6	11	12	10
	UAN	19	23	13	18	22	21	10	20	10	14	16	13
	None	.	.	.	8	10	9	4	14	6	8	8	11
Jun	PM2	23	29	16	39	39	29	49	26	6	12	15	15
	PM	18	22	6	23	20	18	49	18	4	11	11	12
	UAN	21	23	22	22	23	23	42	14	18	14	16	14
	None	.	.	.	9	8	10	4	15	10	8	8	8
Jul	PM2	20	17	4	23	30	30	0	22	0	12	14	-
	PM	16	17	15	6	16	20	5	11	4	10	10	-
	UAN	19	11	12	25	21	24	12	17	0	13	16	-
	None	.	.	.	9	6	11	10	8	10	7	4	-
Aug	PM2	-	8	-	-	-	-	-	10	-	-	12	-
	PM	-	7	-	-	-	-	-	7	-	-	8	-
	UAN	-	12	-	-	-	-	-	7	-	-	14	-
	None	-	.	-	-	-	-	-	9	-	-	6	-
Sep	PM2	-	-	-	-	-	-	-	2	1	-	-	-
	PM	-	-	-	-	-	-	-	0	1	-	-	-
	UAN	-	-	-	-	-	-	-	0	1	-	-	-
	None	-	-	-	-	-	-	-	0	1	-	-	-
Oct	PM2	-	-	-	-	-	-	-	-	10	-	-	-
	PM	-	-	-	-	-	-	-	-	7	-	-	-
	UAN	-	-	-	-	-	-	-	-	14	-	-	-
	None	-	-	-	-	-	-	-	-	0	-	-	-

Table 2.9 ANOVA for total annual NO_3-N losses (1998-2009)

Effect	Num df	Den df	F value	Pr > F
Total Rain	1	76	9.47	0.0029
Treatment	3	5	4.30	0.0751
Cyear	1	76	0.00	0.9675
Cyear2	1	76	1.81	0.1828
Cyear3	1	76	0.83	0.3642
Cyear*Treatment	3	76	1.18	0.3227
Cyear2*Treatment	3	76	2.93	0.0388
Cyear3*Treatment	3	76	1.82	0.1509

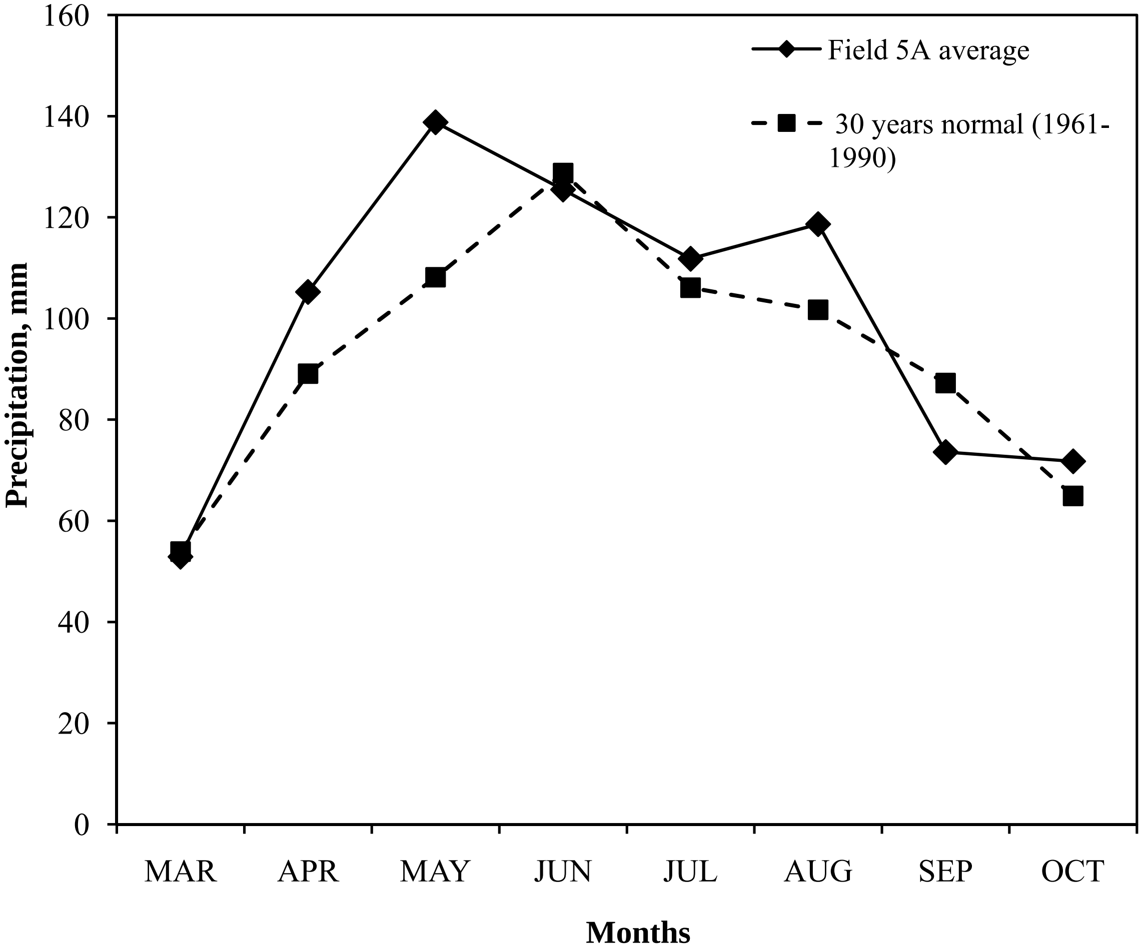


Figure 2.1 Average monthly precipitation distributions at the research site (1998-2009)

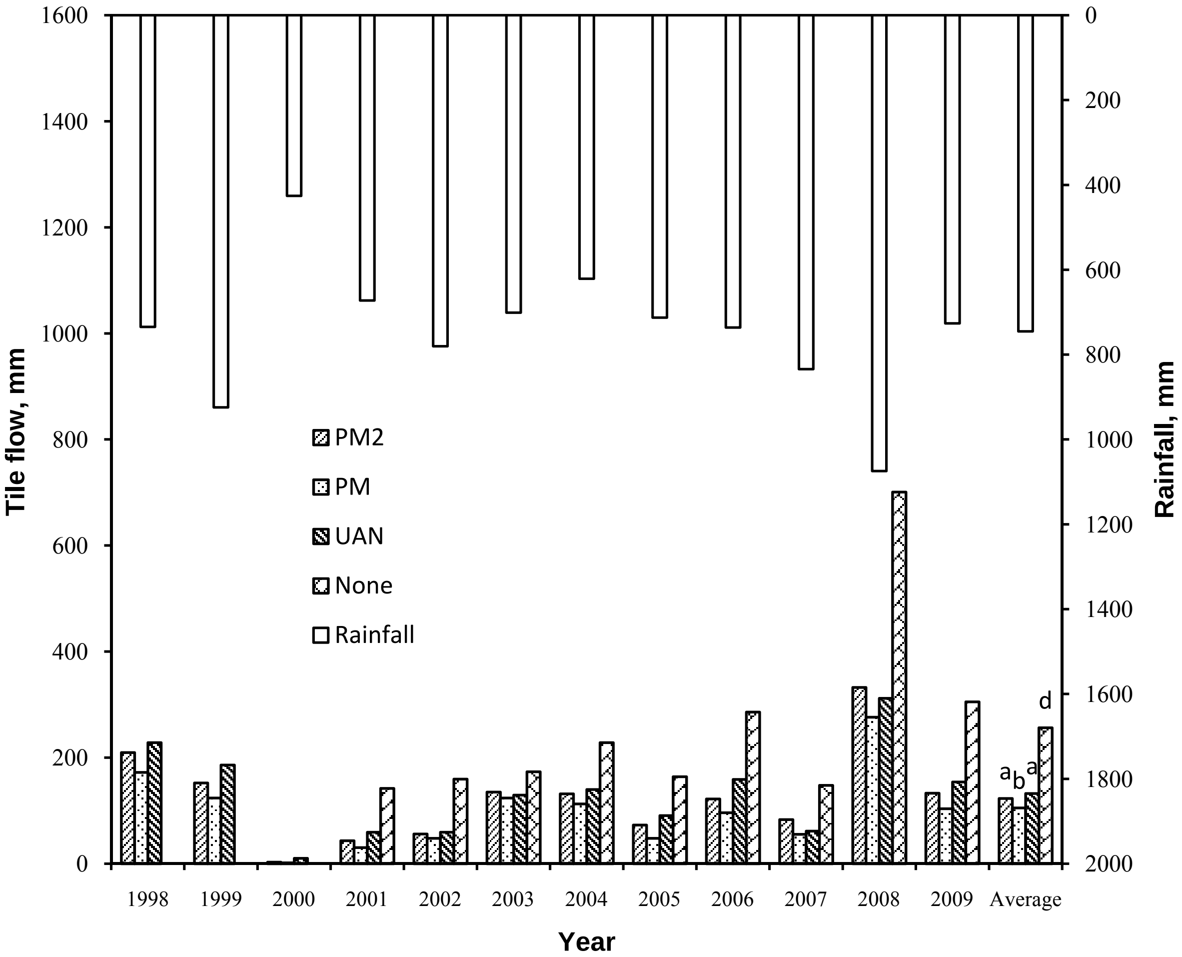


Figure 2.2 Subsurface drainage volumes (mm) as response to precipitation by different N treatments and years

(Values followed by the same letters are not significantly different at α=0.05)

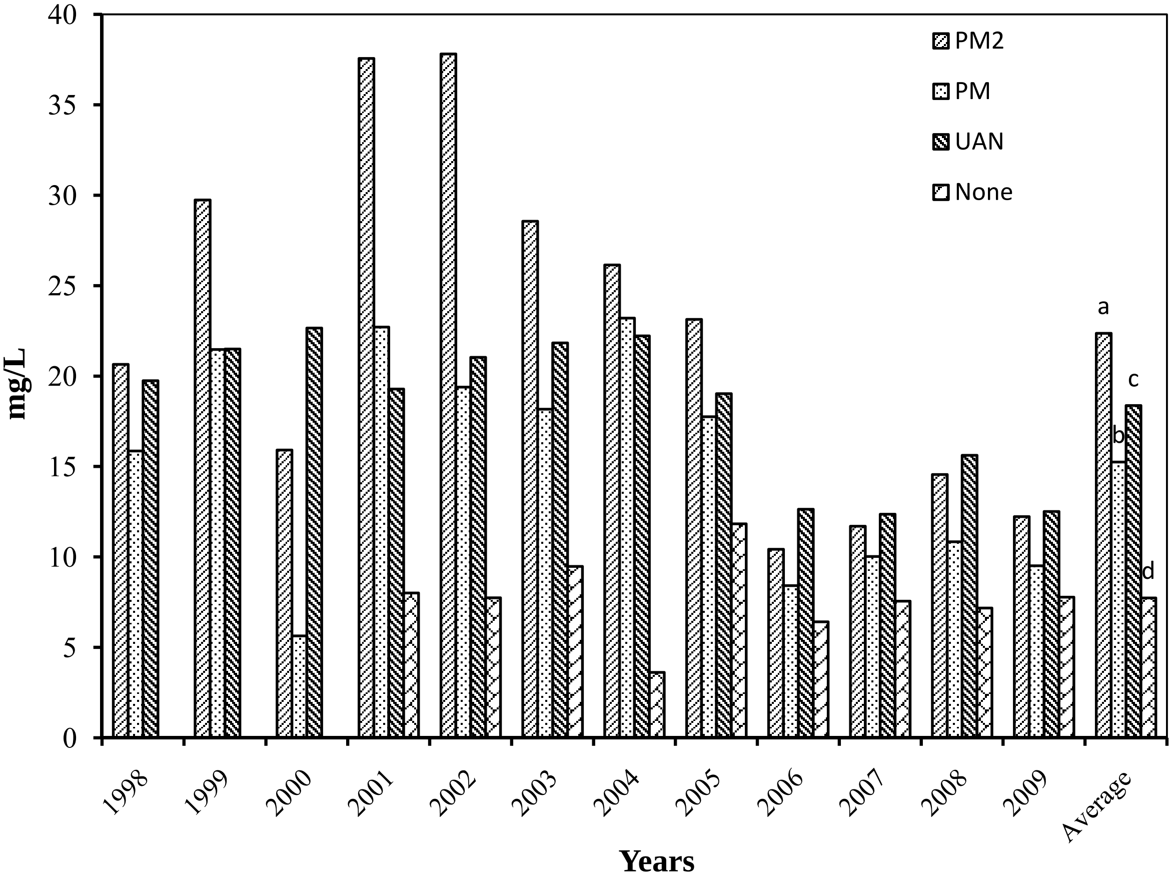


Figure 2.3 Average flow weighted NO_3-N concentration by N treatments and years

(Values followed by the same letters are not significantly different at α=0.05)

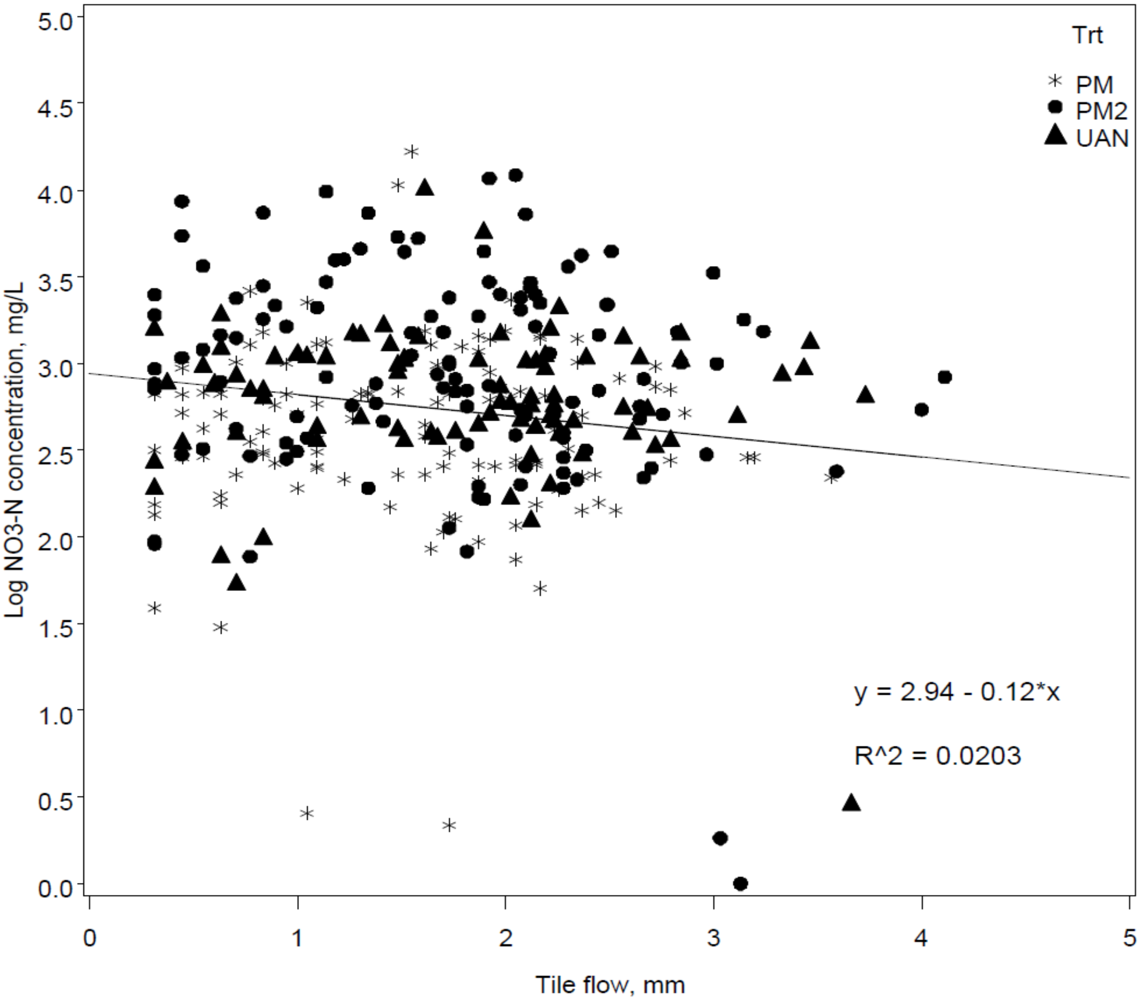


Figure 2.4 Correlation of NO_3-N concentration and tile flow volume

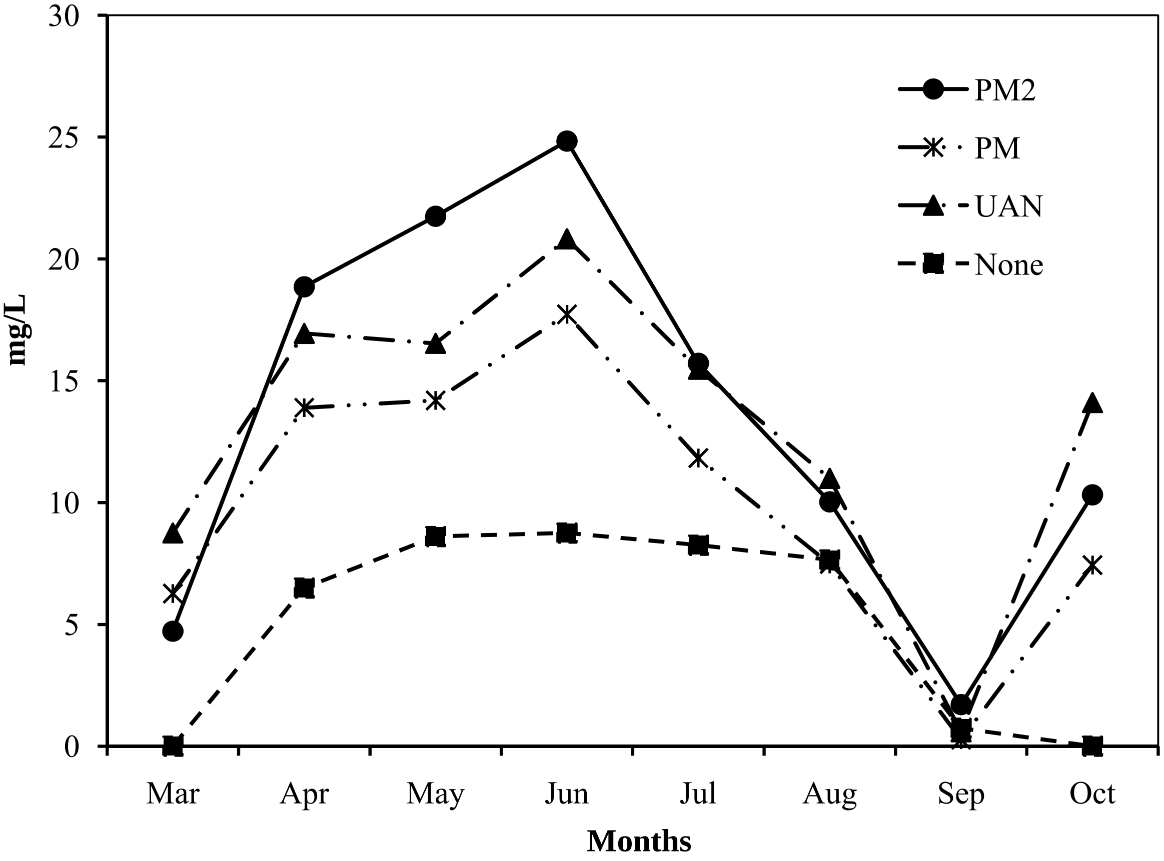


Figure 2.5 Monthly average of flow weighted NO_3-N concentration across N treatments and years

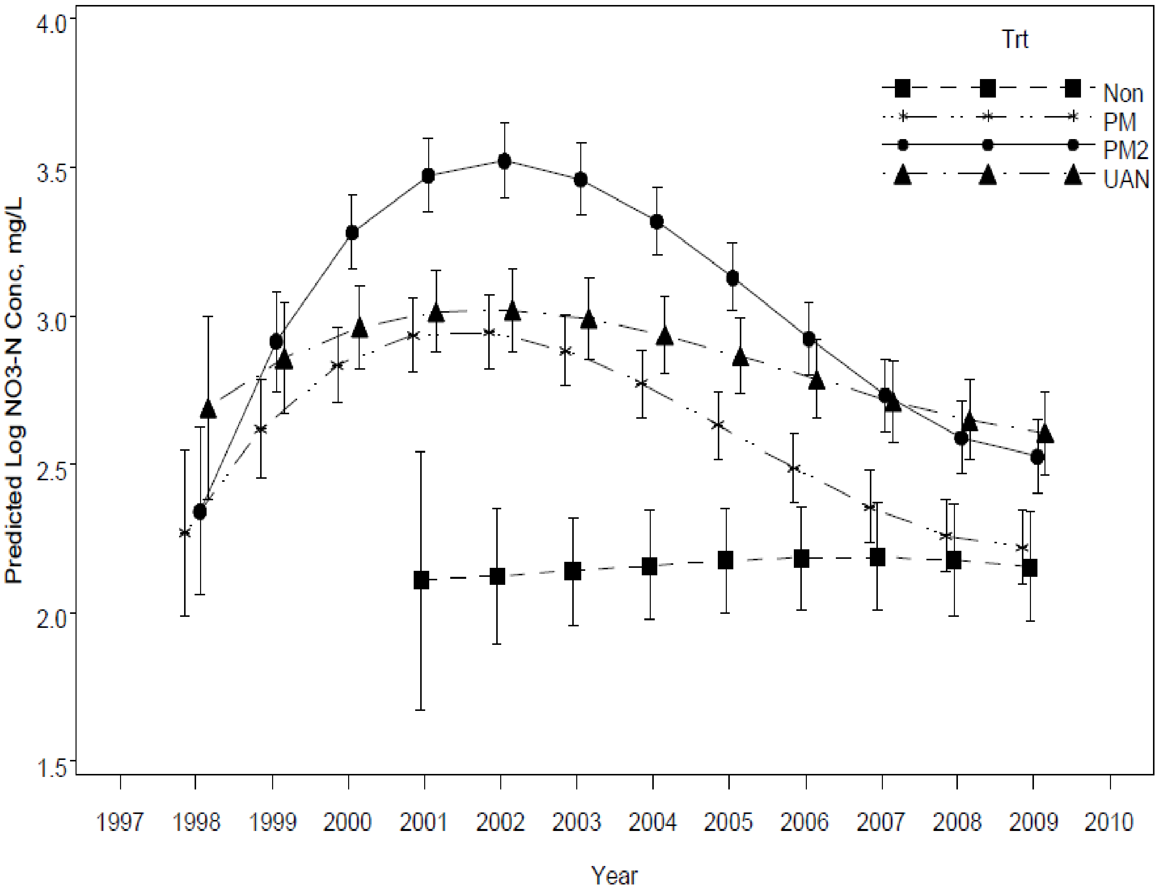


Figure 2.6 Trends of flow weighted NO_3-N concentration in the month of May in response to different N treatments over years

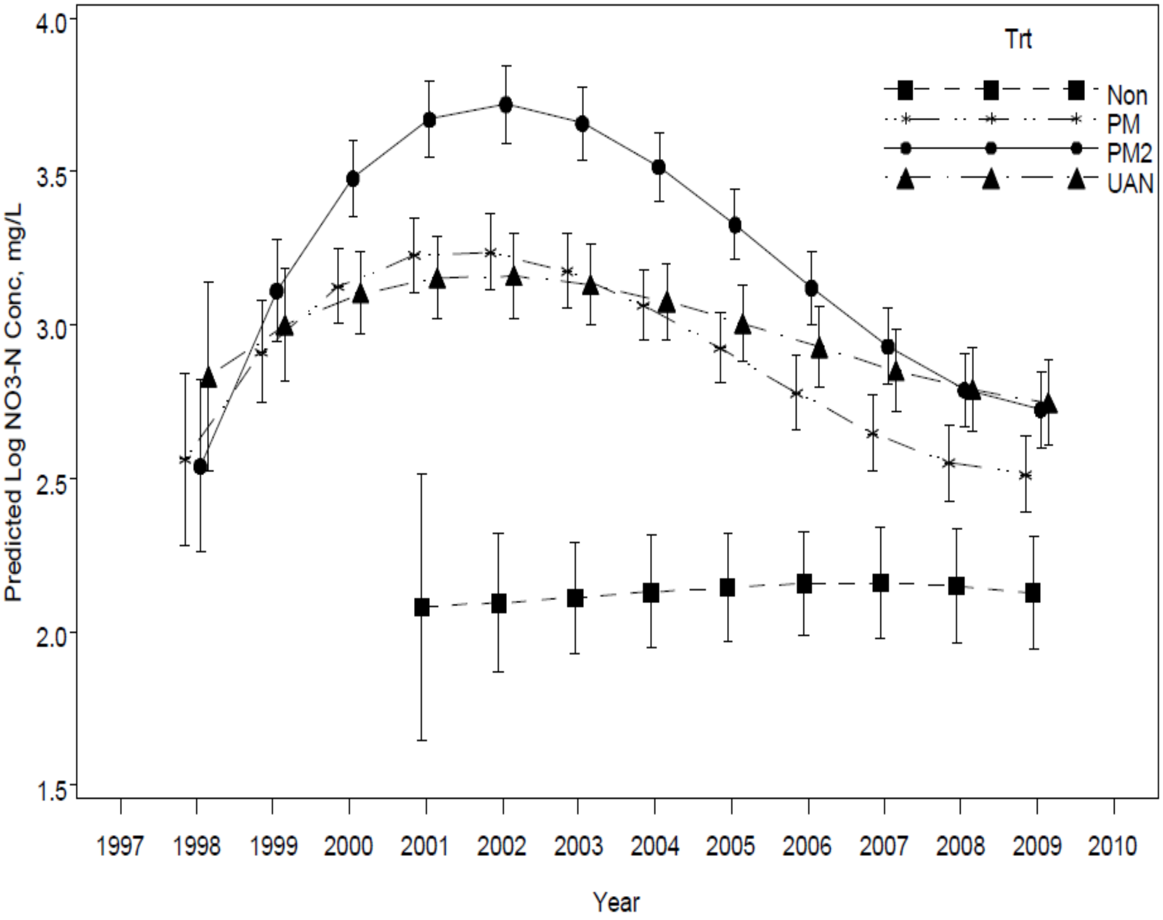


Figure 2.7 Trends of flow weighted NO_3-N concentration in the month of June in response to different N treatments over years

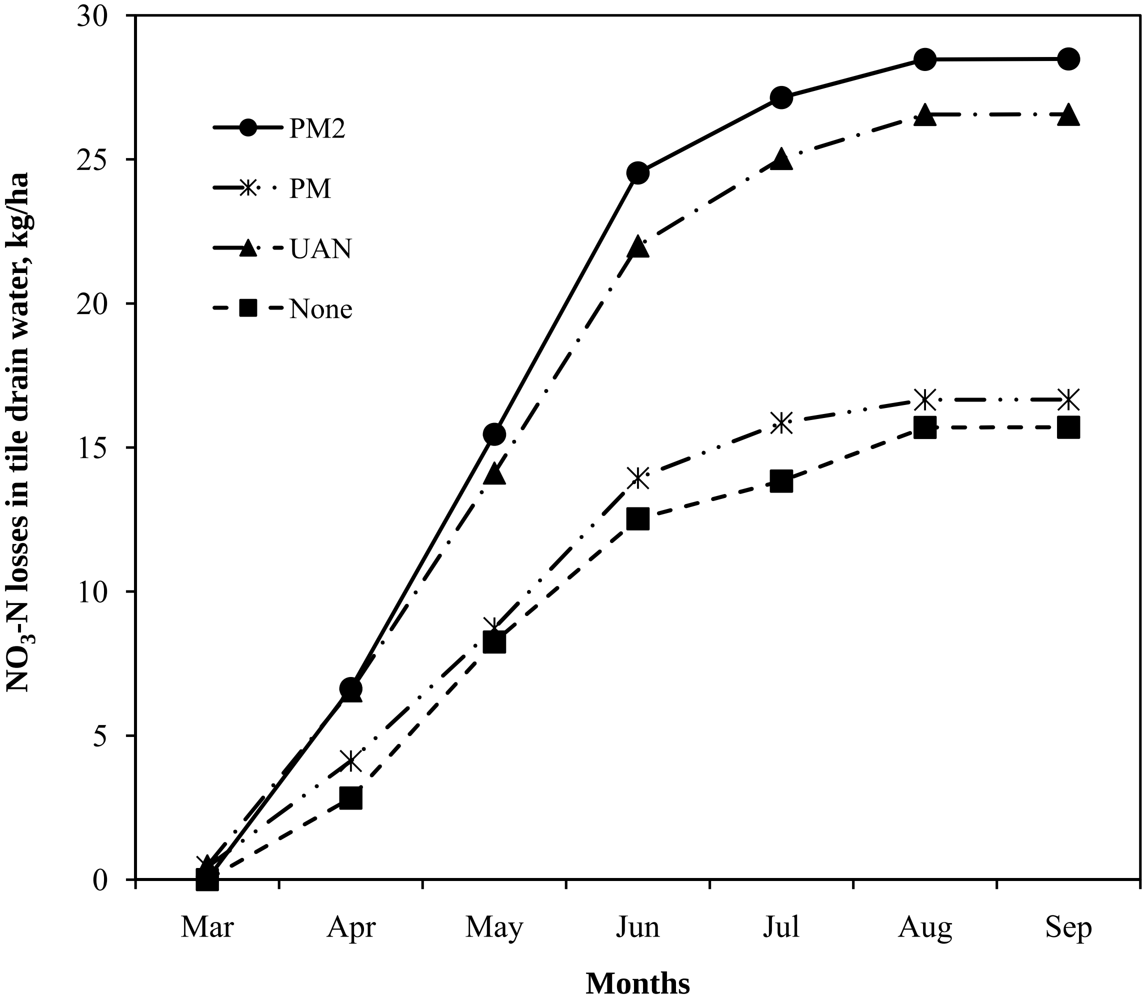


Figure 2.8 Trends of accumulative NO_3-N losses as responses to interaction effects of N treatments and times

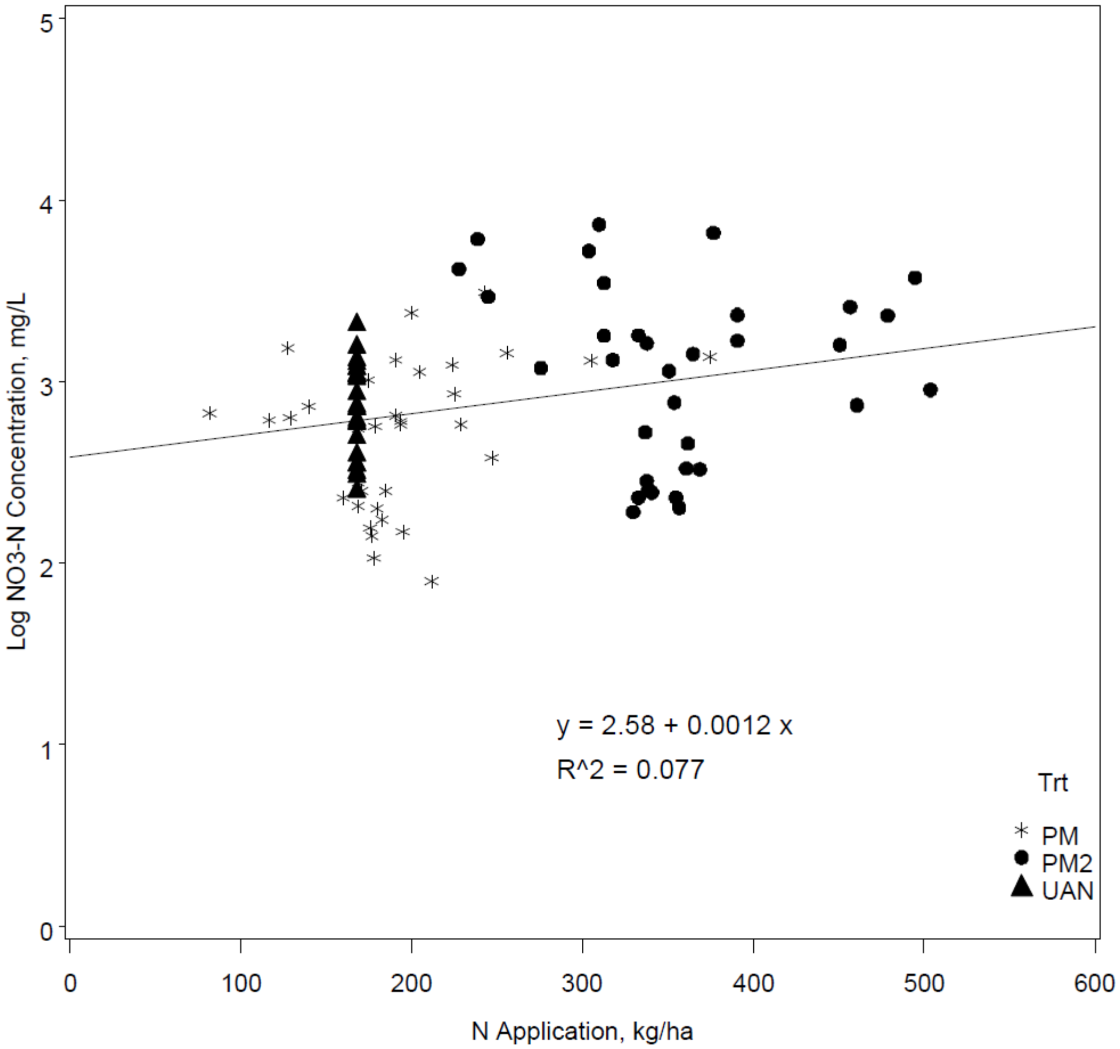


Figure 2.9 Correlation of NO_3-N leaching concentration in tile drain water and N application rates

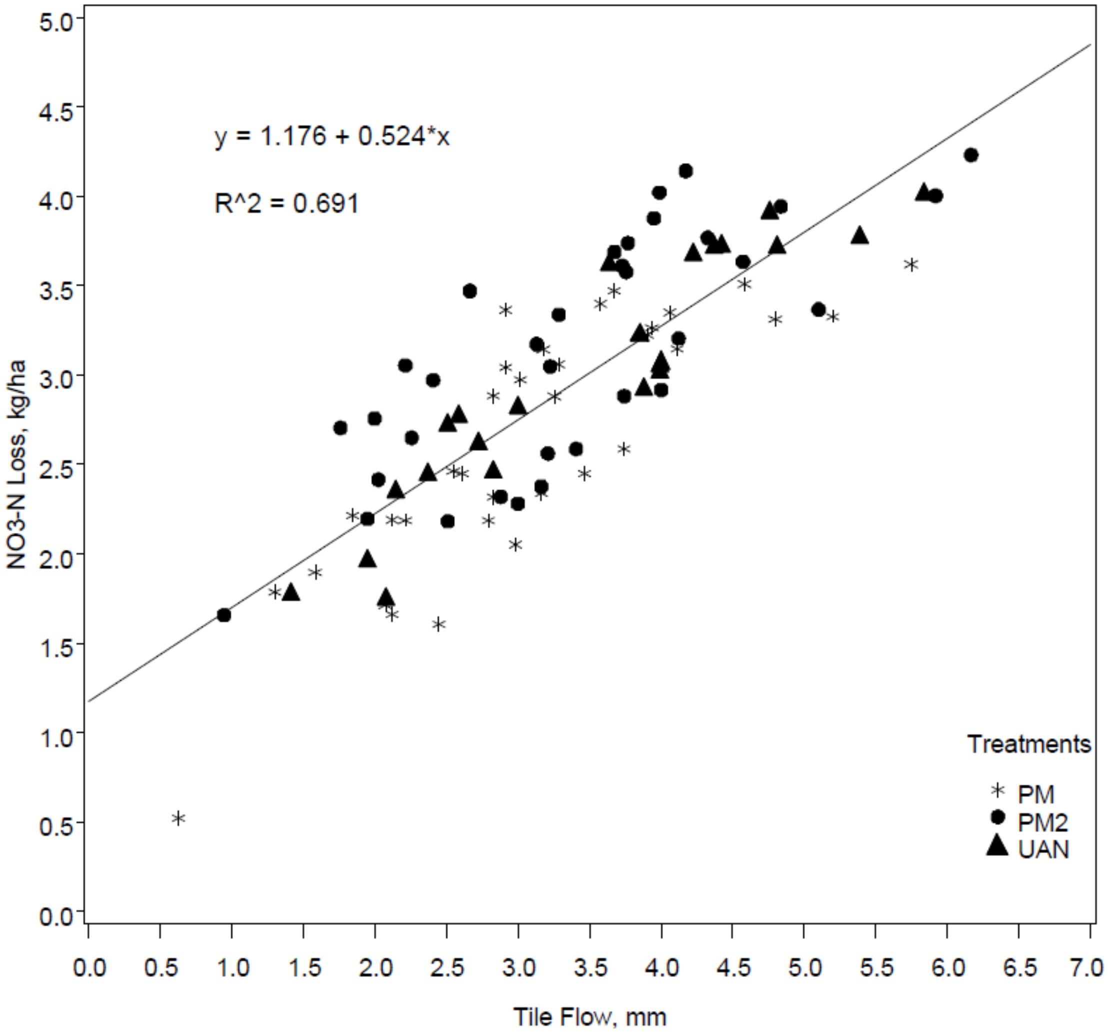
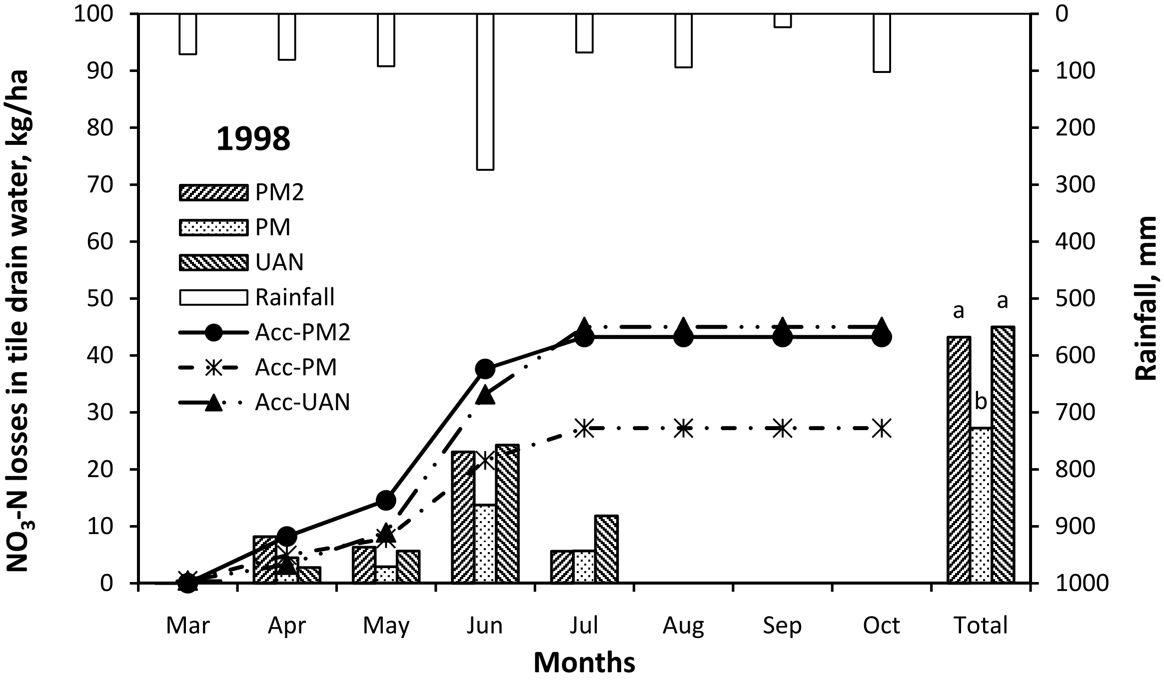


Figure 2.10 Correlation of total NO_3-N losses in subsurface runoff and tile flow



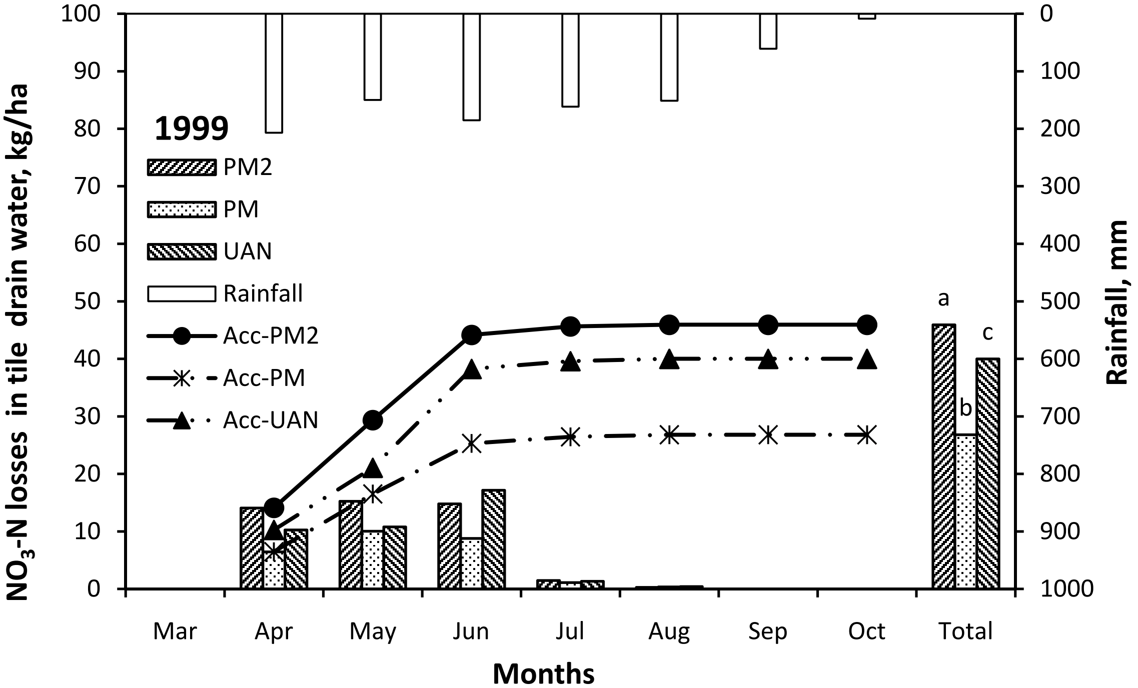


Figure 2.11 Temporal nitrate losses as effects of N treatments and rainfall (1998-1999)

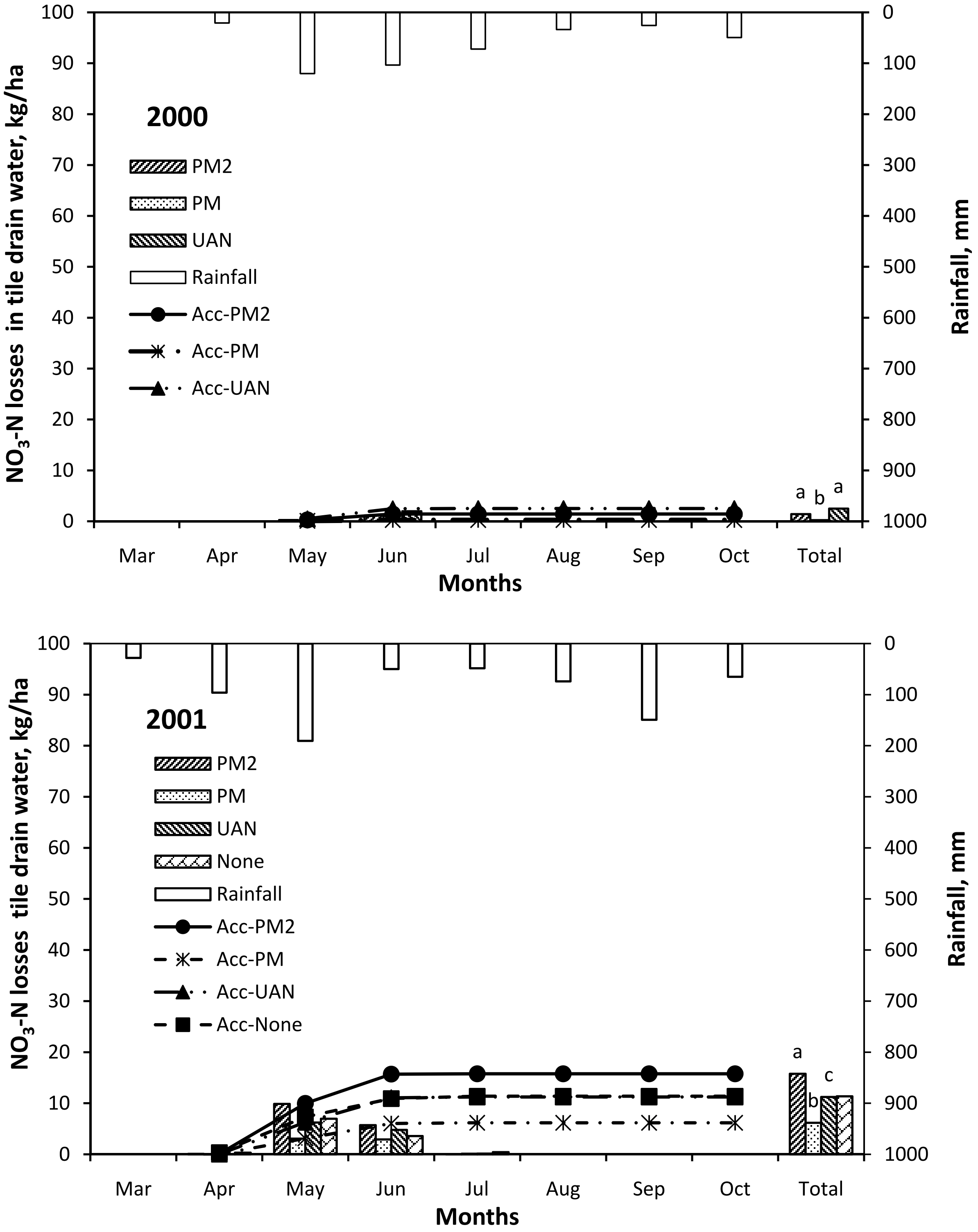


Figure 2.12 Temporal nitrate losses as effects of N treatments and rainfall (2000-2001)

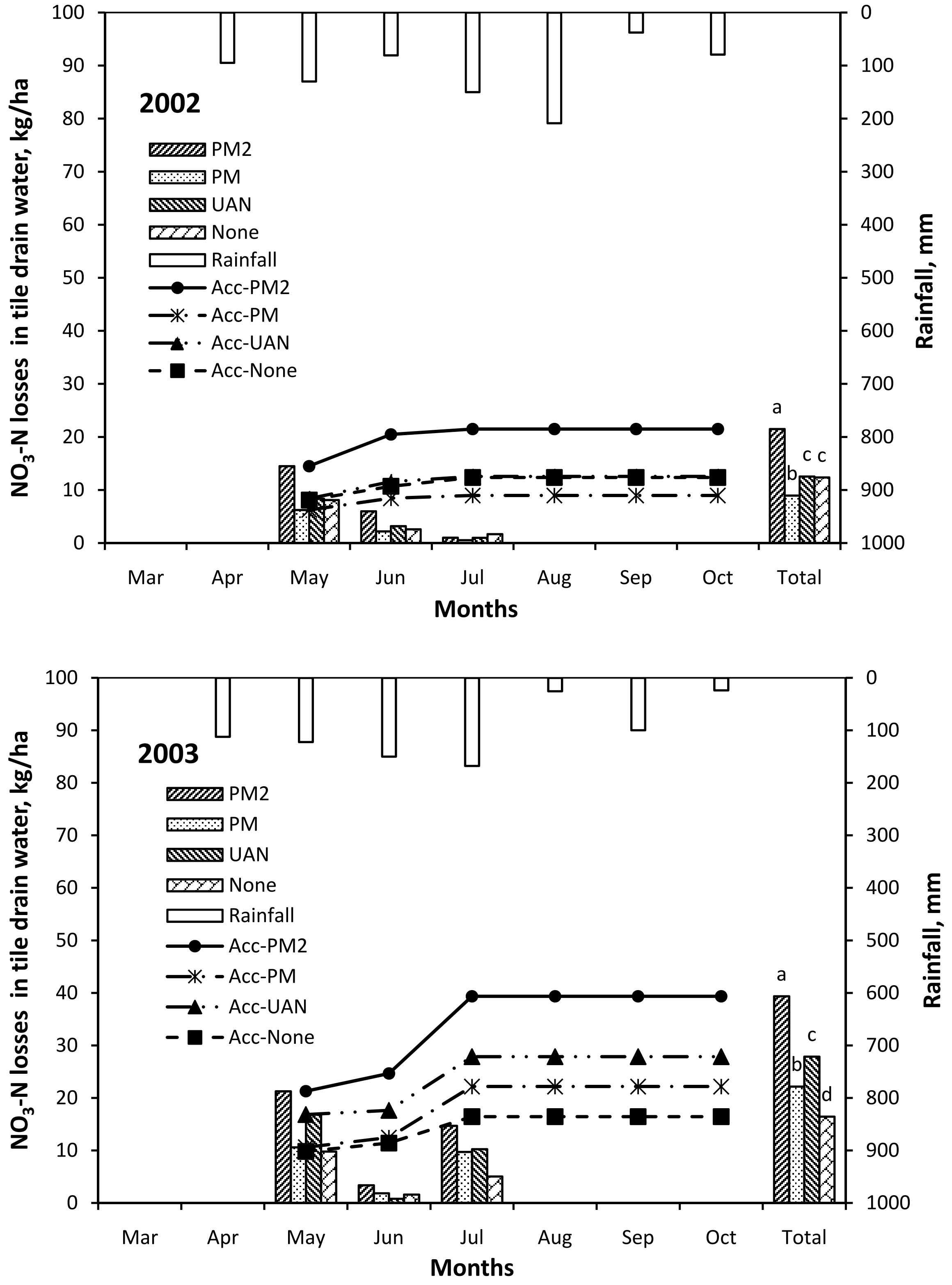


Figure 2.13 Temporal nitrate losses as effects of N treatments and rainfall (2002-2003)

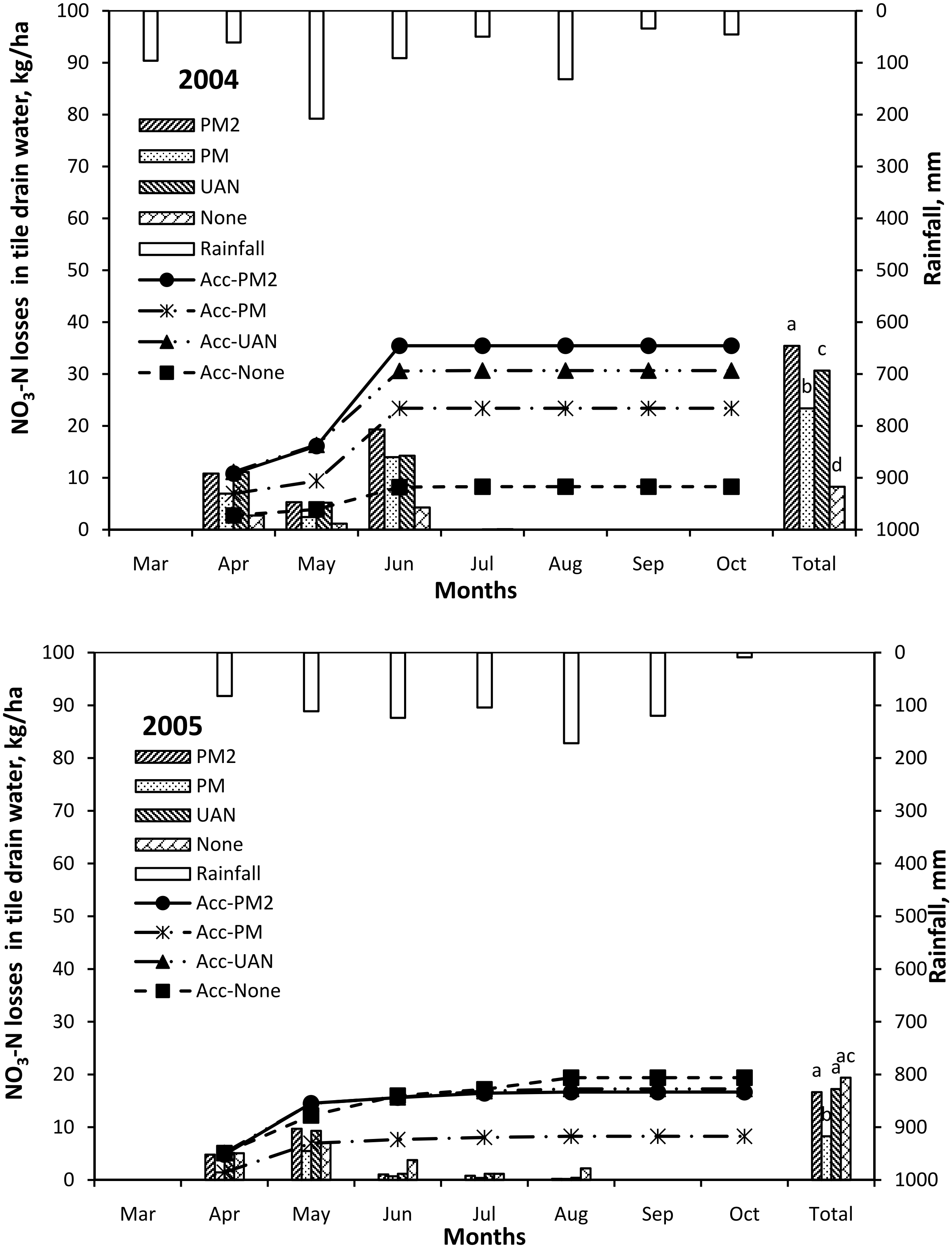


Figure 2.14 Temporal nitrate losses as effects of N treatments and rainfall (2004-2005)

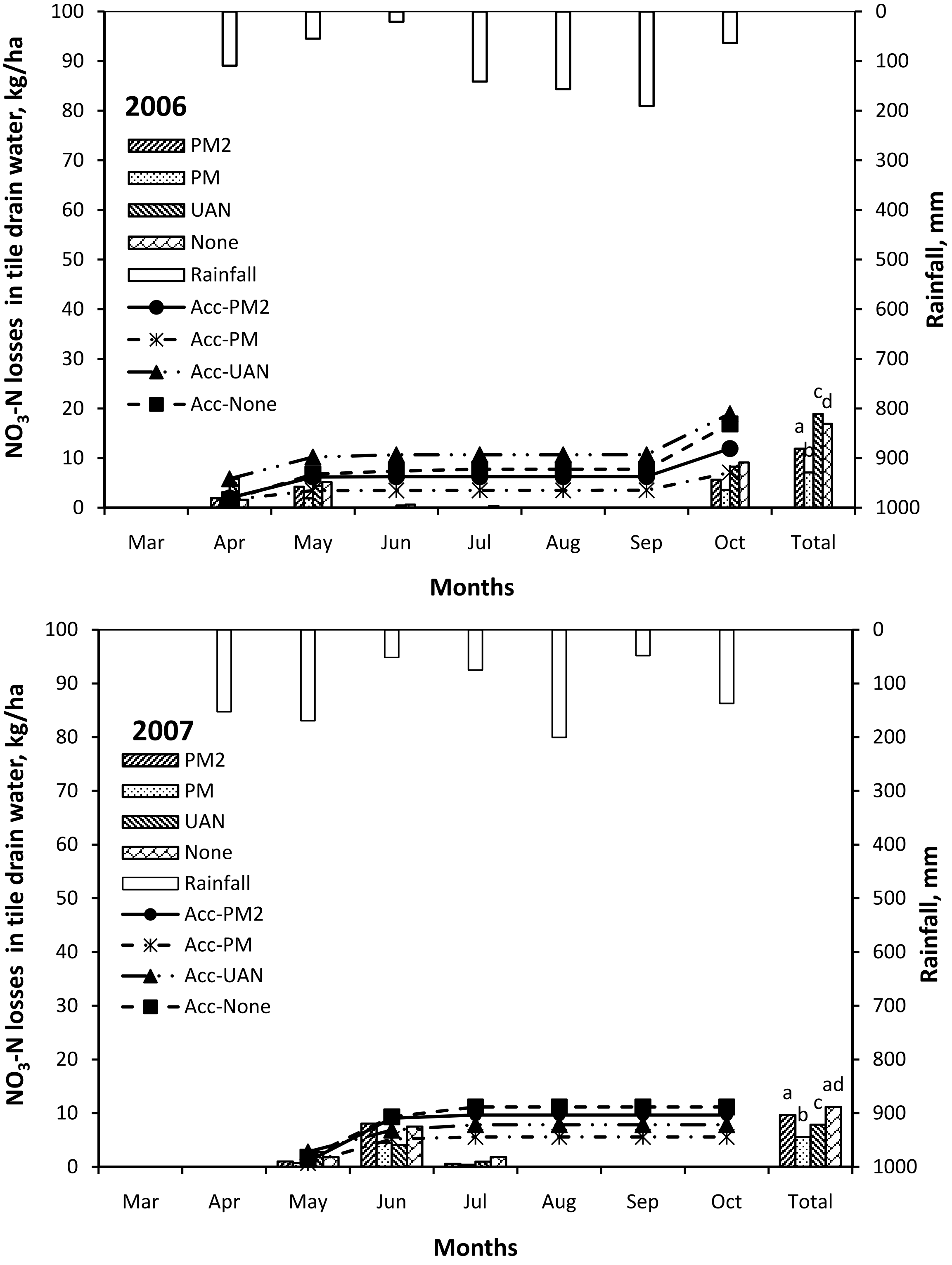


Figure 2.15 Temporal nitrate losses as effects of N treatments and rainfall (2006-2007)

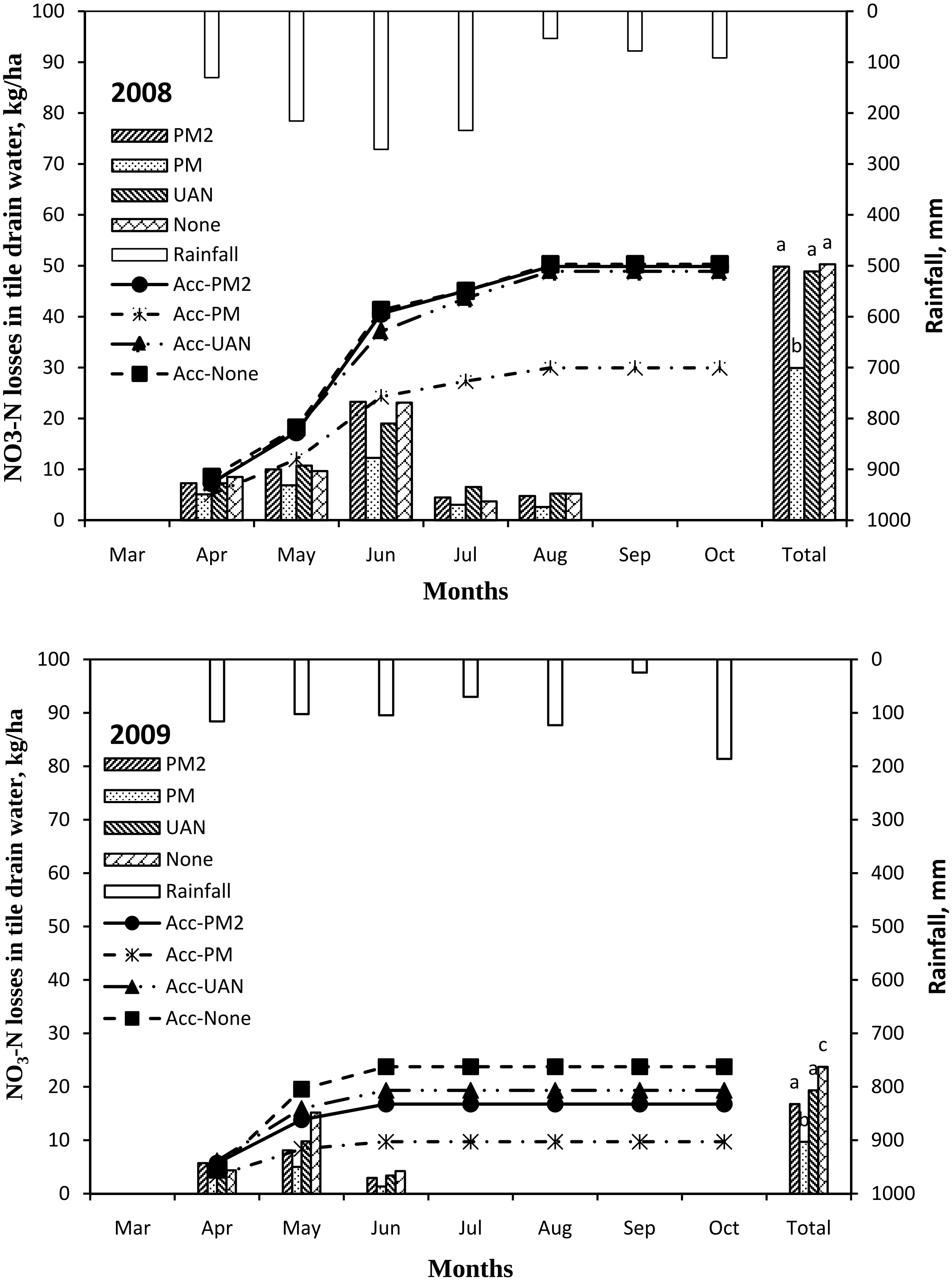


Figure 2.16 Temporal nitrate losses as effects of N treatments and rainfall (2008-2009)

CHAPTER 3. LONG-TERM EFFECTS OF POULTRY MANURE ON CROP YIELD, N UPTAKE AND SOIL NO_3-N RESIDUAL FROM CORN-SOYBEAN PRODUCTION

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(A paper to be submitted to the Transactions of the ASABE)

3.1 Abstract

Repeated surface application of poultry manure on crop field may increase the residual nitrate concentration in top soil if the application rates are beyond the crop uptake potential. Limited information on long-term effects of surface applied poultry manure on corn-soybean production having subsurface drainage system. A long-term study (1998-2009) evaluated the impacts of poultry manure application rates (168 kg-N/ha and 336 kg-N/ha) on crop yield, N uptake and soil NO_3-N residual concentration from a corn-soybean rotation in Iowa. Treatments include urea ammonium nitrate (UAN) with 4 replications, poultry manure at two different rates (168 kg-N/ha and 336 kg-N/ha) with 3 replications for each rates, and a control (0 kg-N/ha). The treatments are applied on eleven field plots (0.1 to 0.4 ha) in an unbalanced randomized complete design. In each field plot, corn is planted on one half and soybean on the other half. Corn and soybean are rotated yearly but only corn side is received the treatment. Soil cores are collected in spring (before planting and applying manure) and in fall (after harvesting and before doing tillage) at the depth of 120 cm from the surface and divided into 5 different depths (0-15, 15-30, 30-60, 60-90, and 90-120 cm). The results of twelve years study indicated that the trends of corn yield are generally increasing over time;

however, on average, the poultry manure (168 kg-N/ha) treatment gives the same corn yield (10.4 Mt/ha vs. 10.1 Mt/ha) but higher soybean yield than UAN (168 kg-N/ha) treatment (3.4 Mt/ha vs. 2.9 Mt/ha). The poultry manure application rates (336 kg-N/ha) only increased 9.6 percent of corn yield and 4.8 percent of soybean yield in compared with those of poultry manure (168 kg-N/ha) treatment. Soil NO_3-N concentrations of all treatments decreased sharply over depths with the averages of Spring soil NO_3-N concentrations were higher than those of Fall soil test. Long-term trends of top soil (0-30 cm) NO_3-N concentration showed that PM2 treatment gives higher NO_3-N residual concentrations than other treatments (PM, UAN and None) with the average as 13.4 vs. 10.8, 10.4, and 8.3 ppm, respectively. Therefore, it may conclude that applying poultry manure at lower rate (168 kg-N/ha) may give the same or better crop yield than chemical fertilizer (UAN) at the same rate and results less NO_3-N residual concentration in soil profile than applying poultry manure at double rate (336 kg-N/ha).

Keywords: poultry manure, subsurface drainage, repeated measures, soil nitrate, corn-soybean rotation

Abbreviation: PM, poultry manure at 168 kg-N/ha; PM2, poultry manure at 336 kg-N/ha; UAN, urea ammonium nitrate (28% liquid) at 168 kg-N/ha.

3.2 Introduction

With the fast and concentrated development of egg industry in Iowa recently, there has been an environmental concern on how to treat the huge volume poultry manure properly and economically. Land application has been used as the best solution for both crop producers and poultry/egg industry in Iowa and other states having the same issues (Edwards and Daniel, 1992; Kingery et al., 1993; Mitchell and Donald, 1999; Moore et al., 1995). Poultry manure contains a high valuable of major nutrient such as N, P, K and other valuable mineral nutrients for crop development. Unlike inorganic fertilizers, the N available for crop use from poultry manure is often lower and slowly released through long mineralization process (Bitzer, 1988; Robinson and Sharpley, 1995; Kingery et al., 1994; Carpenter et al., 1998; Sharpley and Smith, 1995; Mitchell and Tu, 2006). Thus, it has a tendency to over applying poultry manure than the recommended rates in order to compensate this shortage. The built-up of N and P on top soil may increase the potential for nutrient losses via run-off and leaching (Wood et al., 1996; Sharpley et al. 1996; Edwards and Daniel, 1992; Sharpley, 1997; Green et al., 2007). Sharpley et al. (1994) indicated that applying manure on an N basis might help to reduce the nitrate leaching but increase the P built-up on top soil since the ratio of N: P does not often match crop requirements and nutrient removal. Edmeades (2002) summarized the results from 14 long-term experiments on the effects of manure fertilizers on crop production and soil properties and concluded that applying manures did increase the crop yield and significantly change the physical (bulk density, hydraulic conductivity, porosity and aggregate stability) and chemical (soil organic matter, P, K, Ca and Mg content in top soil) properties over long-term application in compared with chemical fertilizers. However, the components of nutrient losses via leaching were not addressed in these reviews. In another study, Cooperband et al. (2002) found that corn yield, N uptake mirror the nitrate concentration in soil profile and revealed that little NO_3-N was released during the first year applied poultry manure. Also, Sainju et al. (2010) conducted a long-term study on impacts of applying poultry manure at 100 kg-N/ha on soil N storage, mineralization, N balance and losses on top soil (0-20 cm) in compare with chemical fertilizer under different tillage systems and found that poultry manure did increase the crop yield, crop residual N biomass, soil N storage and reduce the N losses on top soil. However, the effects of N losses via leaching, volatilization and surface run-off were not included and quantified in these studies. Moore et al. (1995) and Kingery et al., (1993) reported that soil NO_3-N concentration was significantly higher at the 3m depth from litter manure treatment than that of no litter treatments as a results of NO_3-N built-up and downward movement in soil profile. Bakhsh et al. (2001) concluded more NO_3-N concentration in top soil profile may be subject to nitrate losses in run-off or leaching in tile drain water as in subsurface drainage plots. Recently, on a long-term study on southeastern US, Marshall et al. (2001) investigated the long-term effects of broiler litter manure application to pasture on water quality and concluded that land-application of broiler litter at the recommendation rates may have negative impacts on environment on long-term.

Not much information on the long-term effects of poultry manure on crop production and soil NO_3-N residual concentration under a corn-soybean rotation having subsurface drainage as in Midwestern U.S. Therefore, the objective of this study are to evaluate the long-term effects of poultry manure application on crop yield, corn N uptake and soil NO_3-N residual concentration in compared with chemical fertilizer. Such information is needed for better understanding and utilization of poultry manure for corn-soybean production under natural rain-fed condition and subsurface drainage system.

3.3 Materials and Methods

3.3.1 Field experiment design

Field experiments were conducted from 1998 to 2009 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% (Table 3.1). Nicollet soils are characterized as moderately permeable, somewhat poorly drained, produce surface runoff, have high available water capacity, and seasonal high water table (Chinkuyu et al., 2000). Eleven field plots (with sizes varied from 0.19 ha to 0.47 ha) having the 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. 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) was planted on the other half of the same plot followed by the same procedure of crop rotation from the previous years (1998-2009). Fertilizer was applied only on corn side of each field plot. Poultry manure (PM) at two different rates (168 kg-N/ha and 336 kg-N/ha) and a chemical fertilizer (NH_4-NO_3) at a rate of 168 kg-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 0 kg-N/ha for comparison purposes. Corn and soybean residuals are left on the field using moldboard tillage which maintains at least 30% of crop residuals remained on the field. The detailed schedule of agronomic activities on Field 5 is presented on Table 3.2.

3.3.2 Sample collection and analysis

Three poultry manure samples were collected and sent to laboratory in Nevada, IA for analyzing the contents of N, P and K in order to determine the actual poultry manure application rates. The summary of poultry manure characteristics applied on field plots is presented in Table 3.3. A collection of 15 samples of corn stalk cut approximately 15 cm above the soil surface and in 20-cm lengths was collected from each field plot before harvesting corn in Fall. Collection occurred when kernels of corn grain in plant ears formed black residue on 80% of the corn ear surface. The samples are sent to the lab for total N content using the combustion method. The test is aimed to evaluate the effects of fertilizer on the availability of N to the plants and may indicate how critical it is to provide nitrogen for corn development (Blackmer et al., 1989; Veroot et al., 1990).

Three soil cores are collected at the depth approximately 120 cm from the surface in corn side of each field plot in Spring (before applying fertilizer) and in Fall (after harvesting corn). The soil core samples then are divided into five different depths (0-15; 15-30; 30-60; 60-90; 90-120 cm) and combined into a composite sample to represent the soil depth of that plot. Soil samples are air-dried and ground to pass a 2-mm sieve. The soil NO_3-N is extracted with 2 *M* KCl solution and analyzed with a Technicon Autoanalyzer at the Soil Laboratory of Agronomy Department, Iowa State University. Information of post-harvest soil NO_3-N residual helps to measure the NO_3-N not used by corn and evaluate the impacts of N fertilizer application rates on soil quality in long-term application of poultry manure.

3.3.3 Experimental design and statistical data analysis

Eleven field plots were used in this experiment with corn grown in one half of the plot and soybean grown on the other side. Rotation was done yearly for 12 years (1998-2009). Four fertilizer treatments including poultry manure (168 kg-N/ha and 336 kg-N/ha), UAN (168 kg-N/ha) and a control (0 kg-N/ha) were applied on the field plots (only on corn side). All the treatments were arranged in a completely randomized design with unbalance replications due to the lack of land for experiment.

Data from 12 years (1998-2009) of corn and soybean grain yield were analyzed collectively with years as repeated measures (Kaspar et al., 2007; Bakhsh et al., 2010). The MIXED procedure (Littell et al., 1996) of SAS (SAS Institute, 2009) was used in which source of fertilizers, year, rainfall are treated as fixed effects and the plot is considered as random effect. The Compound Symmetry (CS) (for crop yield and N uptake covariance structure are found to be appropriate (based on minimum values of AIC) for the covariance among observations across years within a plot. Details of selection process to choose covariance structure for repeated measures analysis are presented in Littell et al. (1996) and Piepho et al. (2004). Least square means of the fixed effects were computed, and the PDIFF option of the LSMEANS statement was used to display the differences among least square means for comparison. The LSMEAN values were used to compare treatment means and evaluate the treatment effects on crop yield.

Data of soil nitrate residual from field plots are arranged as split-split-plot design with plot, time (year and season) and depth are split level. Data of Spring and Fall soil nitrate are analyzed collectively with years as repeated measures. The top soil NO_3-N data (0 – 30 cm) from 1998 to 2008 after harvest in Fall are used to evaluate the long-term trend of nitrate residual in soil and other correlations of crop yield, N applied rates, nitrate leaching and losses. The data of five depths (0-120cm) from 1998-2006 are used to conduct the analysis of variance (ANOVA) for the effects of N treatments, crop rotation and times. Data from year 2005 was not available for Fall soil test. A comparison of average of first 3 years (1998-2000), second 3 years (2004-2006) and average of ten years (1998-2008) was made to evaluate the long-term trend of nitrate dynamic in soil profile. The LSMEANS statements for depth*treatment is used with a Tukey option to separate the values of soil NO_3-N at certain depths for the comparison purposes. A significant level $\alpha = 0.05$ was used to evaluate the significant difference among all hypothetical testing.

The long-term trends of crop yield, soil nitrate concentration were investigated using with a linear trend component (year is not declared in Class statement in SAS model). The appropriate transformations of data of corn N uptake, is made so that data appear to more closely meet the assumptions of a statistical inference procedure that is to be applied. For these above purposes, the following models were applied for corn yield, soybean yield, N uptake by corn:

Corn yield = (year, fertilizer treatments, fertilizer treatment * year)

Log (N corn stalk) = (fertilizer treatments, year, fertilizer treatments * year)

Soybean yield = (year, fertilizer treatments, fertilizer treatment * year)

Log (Soil NO_3-N) = [treatment, year, season (Fall/Spring), soil depth]

The linear additive model for crop yield is as below:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

Where:

μ: intercept

α: treatment effect

β: year effect

ε: residual

i: treatment (PM, PM2, UAN, None)

j: year

k: plot(treatment)

The statistical analysis was conducted separately for corn and soybean yield data. In all of the statistical analysis, a significant level α = 0.05 was used to evaluate the significant difference among all hypothetical testing. The scope of the linear model analysis in this study is limited to evaluate the trend of crop yields over time under different rates and sources of N fertilizer (poultry manure vs. UAN and control).There are many factors that impact the crop yields such as fertilizer application rates, rainfall amount, growing degree days (GDD), temperature, soil-water condition, etc. Malone et al. (2007) developed more complex empirical regression equations to predict crop yield as a function of rainfall amount, N credit from soybean rotation, N source, N rate and timing of N application.

The relationship of corn grain yield and N application rates (poultry manure and UAN) is evaluated using the quadratic-plus-plateau model as suggested by Cerrato and Blackmer (1990):

"…The quadratic model is defined by equation [1] and [2] as below:

$Y = a + b*X + c*X^2$, if $X< C$ [1]

$Y = P$, if $X > C$ [2]

where Y is the yield of grain (kg/ha) and X is the rate of N application (kg/ha); a (intercept), b (linear coefficient), c (quadratic coefficient), C (critica1 rate of N fertilization, which occurs at the intersection of the quadratic response and the plateau lines), and P (plateau yield) are constants obtained by fitting the model to the data." To fit this model, the data of corn yield and actual N application rates from each field plot annually are used.

3.4 Results and Discussions

3.4.1 Poultry manure characteristics and N application rates

Poultry manure analyses showed that its nutrient and solid matter contents were highly variable throughout the study period. The characteristics of applied poultry manure on field experiments are presented in Table 3.3. Based on these analyses, the calculated N application rates were made for poultry manure treatments every year as in Table 3.4. The analysis of poultry manure over year revealed that to achieve the right target application rates may be difficult but it seems to be comparable in the range close to the 168 kg-N/ha target rate. The moisture content of poultry manure in this study ranged from 25 to 76% which may cause the high variability of N and P percentage in poultry manure over year. Thus, the following comparison will be made on N application rates rather than total poultry manure amount alone.

On average, the actual N application rates on PM and PM2 treatment are 179 kg-N/ha and 336 kg-N/ha respectively. The application rate was low in year 2000 because we were allowing a 10% carryover N credit from manure application in 1998. The nitrogen credit from each kg of soybean yield was given in full 100 percent to the following year at that time. The true targets of 168 kg-N/ha and 336 kg-N/ha are actually obtained when the calculated credits are applied to each plot with the actual N applications. These calculations were based on early calculations when we were unsure of carryover and credit assumptions. After year of 2000, we stopped doing N credit from soybean to following year in poultry manure application rates' calculation. Besides, from the average of actual N and P application rates, it showed that the N: P ratio is not balance from year to year and between PM and PM2 treatments. That may be a cause to faster P built-up or leaching if the amount exceeded crop's need. The recommended rates of N for corn production in Iowa is in the range closed to 168 kg-N/ha (Blackmer et al., 1997; Sawyer et al., 2002) in general. Further long-term studies for better understanding and evaluation of effects of poultry manure application rates on crop yield and soil nitrate residual (Kingery et al., 1994). One of the reasons is the amount of N released from poultry manure is different from chemical fertilizers in which not all N amounts are available after applying manure (Robinson and Sharpley, 1995). Normally, approximately less than 50 percent of N amount in poultry manure is available for crop use, the rest is slowly mineralized or transformed in soil in the following years (Bitzer, 1988; Cabrera et al.,1993; Cooperband et al., 2002; Cabrera and Sims, 2000).

3.4.2 Effects of N treatments on corn and soybean yield

Average corn and soybean grain yields from all N treatments over years are presented in Figure 3.1 and Figure 3.2 respectively. Corn grain yield was significantly higher with PM2 treatments compared with PM and UAN treatments (11.5 Mg/ha vs. 10.4 Mg/ha and 10.1 Mg/ha). Poultry manure treatments (both PM2 and PM) give significantly higher soybean yield than UAN and None treatments overall (3.5 and 3.4 Mg/ha vs. 2.9 and 2.4 Mg/ha). On yearly analysis, there has some years that the trend and patterns of corn yield did not following the overall order of PM2>PM=UAN>None. For example, during the 4 year period (2004-2005), the corn yields from UAN treatment were significantly higher than those of PM treatment ($p<0.05$). The other two following year, the corn yield from UAN treatment were slightly higher than PM treatment but not significant. One of the possible explanations is the abnormal rainfall during this period with higher rainfall in April-June (Table 3.5) may possibly reduce the release of N from applied manure and increase N losses via denitrification. If the Late Spring Soil Nitrogen Test (LSNT) were conducted in accompany with the experiment, it might provide better verification for the claims. Many previous studies did show the strong correlation of LSNT information to predict corn yield and the sufficient nutrient content in soil to achieve a good corn yield (Shartall and Liebhardt, 1975; Blackmer et al., 1989; Blackmer and Schepers, 1994; Ferguson et al., 2002; Fox, 1989; Jokela, 1992). By using a computer model, Bittman et al., (2001) also indicated the impacts of poultry manure on N cycling during the crop season and reported that the N available for plant use from poultry manure was lower in wet weather scenarios than normal ones.

Also, the results of crop yield comparison as in Table 3.6 showed that double poultry manure application rate to 336 kg-N/ha only increased 9.8% for corn yield and 4% for soybean yield on average in comparison to those of PM treatment. There is no significant difference on corn yield between PM and UAN treatment (p=0.596). PM treatment gives higher soybean yield than UAN treatment (p=0.048). On average, the orders of crop yield as response to different N treatment are PM2>PM=UAN>None for corn and PM2=PM>UAN>None for soybean. The rotation effects are estimated by comparing the crop yield on odd vs. even years since corn and soybean are planted on the same plot. The results showed that there is no significantly difference across the responses of different N treatments between odd vs. even years (p<0.0001) but the long-term trends of corn yield are increasing over times. Therefore, it may be concluded that overall, applying poultry manure at lower rate (168 kg-N/ha) may give the comparable crop yield to that of chemical fertilizer at the same rate over long-term.

3.4.3 Effects of N treatments on N uptake

Corn stalk N test was conducted before harvesting corn by collecting a portion of corn stalk at the height about 15-40 cm from the ground. Generally, a threshold value of 2000 ppm nitrate nitrogen concentration in corn stalk is considered as an indication of excessive N applies (Wilhelm et al., 2005; Varvel et al., 1997; Smiths and Sharpley, 1990; and Balkcom et al., 2003). Table 3.7 presents the average of corn stalk N uptake values as a response to different N treatments over time. Overall, the results showed the PM2 treatment gives the highest N content in corn stalk (2879 ppm) in compared with UAN (1135 ppm), PM (909 ppm) and None (31 ppm). Highly variability of N corn stalk from PM2, PM and UAN treatments are observed with an exceptional high value on 2000 for PM2 (12725 ppm) treatment and very low value on 2009 for PM treatment (12). The relation of corn yield and corn N uptake are not strongly correlated (Figure 3.3). Therefore, it may suggest that increasing sample size in each field plot for corn stalk and the timing of sample collection should be revised in order to obtain better information of corn N uptake. However, the consistent low values of corn stalk N in three constitution years (2004-2006) in compared with those of UAN treatment would help to explain why the corn yields are lower for PM treatment than those of UAN.

3.4.4 Effects of N treatments on soil residual NO_3-N concentration

Soil NO_3-N residual evaluation include Spring and Fall soil tests. Spring soil test was conducted to estimate the initial NO_3-N concentration in soil profile before applying manure. The post harvesting soil nitrate test (PHNT) is conducted in Fall on corn side to measure the residual soil nitrate residual concentration after corn harvest. This amount might be possibly lost by leaching and denitrification if there is no winter cover crop or at early precipitation in crop growing season (April-May). Long-term trends of top soil (0-30cm) NO_3-N is presented in Figure 3.4. The top soil NO_3-N residual concentration varied with times and highly affected by rainfall and crop removal rates rather than the N application rates as expected with the mobility of nitrate in soil. Overall, PM2 treatment has significantly higher soil NO_3-N on top soil (0-30 cm) than other treatments ($p<0.05$). No significant difference was found between PM and UAN treatment on top soil NO_3-N residual concentration. The seasonal effects of fertilizer on N dynamic in soil are evaluated by comparing the average of soil NO_3-N concentrations in Spring and Fall in Figure 3.5. The analysis of variance for soil nitrate concentration (Table 3.9) results showed the significant interaction effects of N treatments, season and depth across years in which average of top soil NO_3-N concentration in Fall are significantly lower than those of in Spring. It seems reasonable due to the fact that N fixation from soybean in previous year and N mineralization processes in soil. Similarly, the long-term trends of soil NO_3-N residual concentration in Fall (Figure 3.6) showed that soil NO_3-N residual concentrations highly varied with depths, N treatments over times but PM treatment was likely to have lower NO_3-N concentration at the depth > 30cm in comparison with those of PM2 and UAN treatments.

Correlation of corn yield and N application rates (either poultry manure or chemical fertilizer) is shown in Figure 3.7. Overall, the increase of N applied rates showed an increase in corn yield but excessive N application did also show the decline in corn yield for PM2 treatment. Also, soil NO_3-N residual concentration shows little effects on nitrate concentration in tile drain water (R^2=0.099, $p>0.05$).

The relationship of corn yield and top soil (0-30cm) NO_3-N concentration is presented in Figure 3.9. The conversion process for this correlation is made following the process as described in Nelson et al. (1965), Dow et al., (1969) and Gardner (1971). The results show that there is no strong relationship of soil nitrate residual with corn yield annually. The influences of crop yield, N applied rates and soil NO_3-N residual on top soil showed that applying poultry manure at lower rate (168kg-N/ha) still maintains the high crop yield but has significantly lower soil NO_3-N residual concentration on top soil profile (Table 3.10).

3.5 Conclusions

A long-term study (1998-2009) was conducted to evaluate the effects of poultry manure application rates (168 kg-N/ha and 336 kg-N/ha) on crop yield, N uptake and soil

NO_3-N residual concentration from a corn-soybean rotation system having a subsurface drainage in Iowa. The results suggested that long-term trends of applying poultry manure showed significantly increase in crop yield (corn and soybean) over years in compared with those of UAN and control treatments. However, over applying poultry manure may result a higher soil nitrate residual concentration in top soil and increase a possibility of nitrate downward movement in lower depth of soil profile under long-term applied poultry manure. Thus, the PM treatment (168 kg-N/ha) appears to give comparable crop yield but lower soil nitrate concentration in top soil than chemical fertilizer (UAN) at the same rate.

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Table 3.1 Selected soil characteristics from Field 5A (Nicolette loamy soil)

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	Bulk density (mg/m^3)	Organic matter (%)
15	31.3	43.6	25.1	7.3	1.20	4.3
30	31.2	42.8	26.0	6.7	1.30	4.0
60	27.7	42.2	30.1	6.9	1.35	2.9

*Adapted from Chinkuyu et al. (2002)

Table 3.2 Agronomic field activities at the research sites

Year	**Field activities**					
	Manure application	UAN application	Corn Planting	Soybean Planting	Harvesting corn	Harvesting soybean
	---------------------------Dates------------------------					
1998	Apr 29	May 1	May 8	May 8	Oct 19	Sep 30
1999	May 4	May 4	May 10	May 10	Oct 14	Oct 12
2000	Apr 13	May 5	May 8	May 8	Sep 20	Oct 4
2001	May 17	May 17	May 18	May 18	Oct 15	Oct 17
2002	May 3	May 3	May 22	May 22	Oct 18	Oct 15
2003	May 16	May 16	--	--	Oct 9	Sep 25
2004	Apr 28	Apr 29	May 3	May 11	Oct 8	Sep 27
2005	May 10	May 10	--	--	Oct 14	Oct 10
2006	May 15	May 15	--	--	Oct 23	Oct 25
2007	May 21	May 21	--	--	Oct 30	Oct 30
2008	May 22	May 22	May 22	May 22	Oct 27	Oct 20
2009	May 12	May 12	May 14	May 14	Oct 12	Sep 30

Table 3.3 Poultry manure analysis and average N application rates over years

Year	% as TKN	% as Ammonia N	% as K_2O	% as P_2O_5	% H_2O
1998	1.5	1.1	1.3	1.0	47.5
1999	3.0	0.8	2.1	4.3	49.8
2000	3.2	0.8	2.3	3.9	32.4
2001	2.2	1.6	2.0	2.7	57.0
2002	1.6	0.7	0.6	1.1	53.7
2003	1.9	0.9	1.1	1.4	74.6
2004	2.4	1.6	1.1	2.1	69.9
2005	2.1	0.2	3.1	6.1	25.0
2006	2.0	1.0	1.2	2.6	58.4
2007	1.8	1.0	1.4	1.0	76.3
2008	2.2	.	1.1	2.0	59.1
2009	2.7	0.7	1.7	1.9	58.4
Average	2.2	0.9	1.6	2.5	55.2
Std. Error	0.1	0.1	0.4	0.2	0.4

Table 3.4 Average N poultry manure application rates to field plots over times

	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	10632	160	108	153	23163	352	220	300
1999	9866	301	439	230	14953	446	630	278
2000	3254	87	128	79	8872	331	333	199
2001	9013	195	245	181	15318	331	416	308
2002	8063	132	87	49	14468	237	156	88
2003	11565	124	159	123	18636	345	255	198
2004	10364	249	218	117	20006	480	420	226
2005	8871	186	541	278	16725	351	1020	525
2006	9703	195	247	115	17000	342	434	201
2007	9632	171	95	133	19542	346	194	270
2008	8059	164	250	91	15872	324	232	179
2009	6591	180	124	232	13312	363	250	115
Average	8801	179	220	148	16489	354	380	241
Std. Error	633	16	41	20	1057	17	70	32

Table 3.5 Precipitation at research site during the study period (1998-2009)

	Month								Growing Season (May-Sep)	Drainage Season (Mar-Oct)
Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		
					(mm)					
1998	71	81	92	274	68	94	24	102	552	806
1999	25	207	150	185	162	151	61	9	709	949
2000	11	21	120	104	72	34	26	50	356	437
2001	28	96	190	50	48	74	149	65	511	700
2002	10	95	130	81	150	209	38	79	606	790
2003	29	112	122	150	168	25	100	24	565	730
2004	96	61	208	91	50	132	34	45	515	717
2005	35	82	111	124	104	172	111	9	622	748
2006	74	109	55	21	141	156	191	63	564	811
2007	81	153	169	52	75	200	48	137	545	915
2008	71	130	216	271	234	53	78	92	852	1145
2009	103	116	102	104	70	123	24	186	424	829
Average	53	105	139	125	112	119	74	72	568	798
Normal	54	89	108	129	106	102	87	65	532	740

Table 3.6 ANOVA table for fixed effects of corn and soybean yield, N uptake in corn stalk

Effects	Num df	**Den df**	**F value**	**Pr > F**
Corn yield				
Treatment	3	7	16.44	0.0015
Year	11	77	19.91	<0.0001
Treatment*year	33	77	4.85	<0.0001
Trend of corn yield	-------------------	-------------------	-------------------	-------------------
Treatment	3	7	9.07	0.0083
Cyear	1	117	53.49	<0.0001
Cyear*Treatment	3	117	8.05	<0.0001
Corn N uptake	-------------------	-------------------	-------------------	-------------------
Treatment	3	73	80.97	<0.0001
Year	10	73	8.5	<0.0001
Treatment*year	30	73	3.71	<0.0001
Soybean yield	-------------------	-------------------	-------------------	-------------------
Treatment	3	7	6.43	0.0202
Year	11	77	35.81	<0.0001
Treatment*year	33	77	1.91	0.0107
Trend of soybean yield	-------------------	-------------------	-------------------	-------------------
Treatment	3	7	0.92	0.4801
Cyear	1	117	6.28	0.0136
Cyear*Treatment	3	117	1.43	0.2383

Table 3.7 Effects of N application rates on N uptake in corn stalk

	N application rates			
Year	**PM2**	**PM**	**UAN**	**None**
	N concentration in corn stalk, ppm			
1998	3299	763	186	38
1999	3895	2519	784	15
2000	12725	3723	2430	43
2001	3590	1123	1290	20
2002	1242	57	1791	18
2003	3777	1604	2403	7
2004	1087	61	225	99
2005	17	24	1503	9
2006	425	20	489	20
2007	-	-	-	-
2008	1346	98	134	64
2009	262	12	1245	10
Average	2879^a	909^b	1135^b	31^c

(Note: Values on the same row having the same letter are not statistically significant difference from each other at α = 0.05)

Table 3.8 Selected estimates for comparisons of crop yield and N uptake among N treatments over years

Labels	Estimates	Standard Error	df	t value	Pr > |t|
Corn yield					
PM2 vs UAN	1392.33	501.37	7	2.78	0.0274
PM vs UAN	278.11	501.37	7	0.55	0.5964
PM vs PM2	-1114.22	535.99	7	-2.08	0.0762
None vs PM	-4191.03	758.01	7	-5.53	0.0009
None vs PM2	-5305.25	758.01	7	-7.00	0.0002
None vs UAN	-3912.92	733.94	7	-5.33	0.0011
Corn N stalk	--				
PM2 vs UAN	0.77	0.21	73	3.74	0.0004
PM vs UAN	-1.23	0.21	73	-5.95	<0.0001
PM2 vs PM	-2.00	0.21	73	-9.41	<0.0001
Soybean yield	--				
PM2 vs UAN	633.79	202.43	7	3.13	0.0166
PM vs UAN	483.38	202.43	7	2.39	0.0483
PM vs PM2	-150.42	216.41	7	-0.70	0.5094
None vs PM	-941.67	306.05	7	-3.08	0.0179
None vs PM2	-1092.08	306.05	7	-3.57	0.0091
None vs UAN	-458.29	296.33	7	-1.55	0.1659
Odd vs Even (years)	-271.22	54.5106	77	-4.98	>0.05

Table 3.9 ANOVA for soil NO_3-N concentration over times (1998-2006)

Effects	Num df	Den df	F value	Pr > F
Treatment	3	7	13.31	0.0028
Depth	4	645	191.83	<0.0001
Treatment*depth	12	645	0.72	0.7338
Year	7	645	8.50	<0.0001
Treatment*year	21	645	0.99	0.4747
Year*depth	28	645	6.53	<0.0001
Treatment*year*depth	84	645	1.32	0.0368

Table 3.10 Influence of soil nitrogen levels on corn yields response to different N treatments

		Soil sample depth in cm			
		Before planting (Spring)*		After harvesting (Fall)**	
N applied rates	Corn yield‡	0-15	15-30	0-15	15-30
kg/ha	kg/ha	-------------------------- NO_3-N, ppm ---------------------			
PM2 (336)	11,502^{a}	19.5^{a}	9.4^{a}	14.8^{a}	10.8^{a}
PM (168)	10,400^{b}	19.6^{a}	10.2^{a}	11.5^{b}	6.8^{b}
UAN (168)	10,065^{b}	25.2^{b}	11.0^{ab}	10.7^{b}	8.3^{b}
None (0)	5,987^{c}	15.5^{c}	8.3^{ac}	6.7^{c}	5.5^{bc}

*Spring soil test is stopped collecting in 2005. Data of years 2007 and 2008 are excluded in this table.

**Fall soil test results are available for ten years (1998-2004 and 2006-2008)

‡ Values in the same column followed by the same letter were not significantly different at significant level $\alpha = 0.05$.

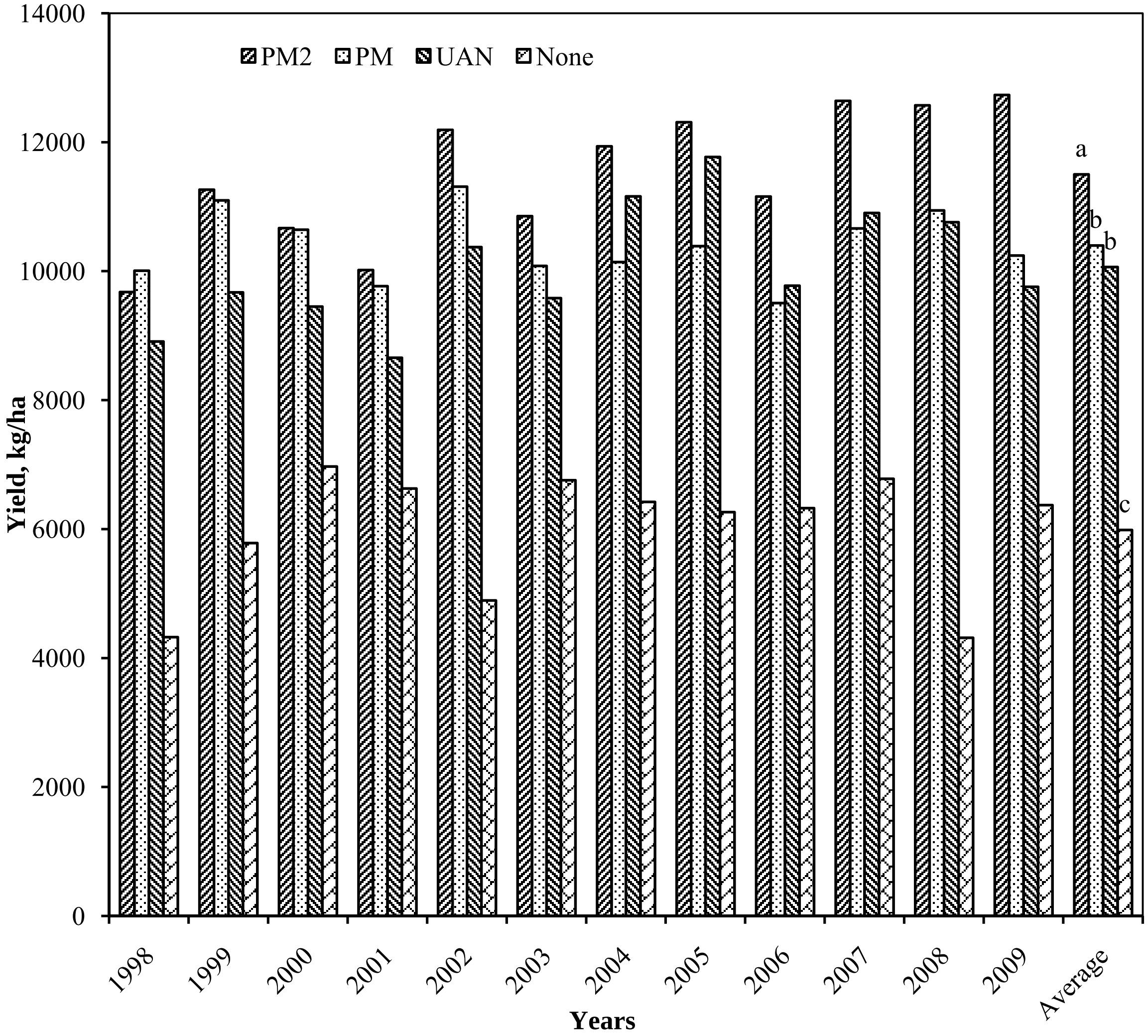

Figure 3.1 Average of corn yield as response to different types of N treatments over years

(Values having the same letter on top of the column are not significantly differences at α =0.05)

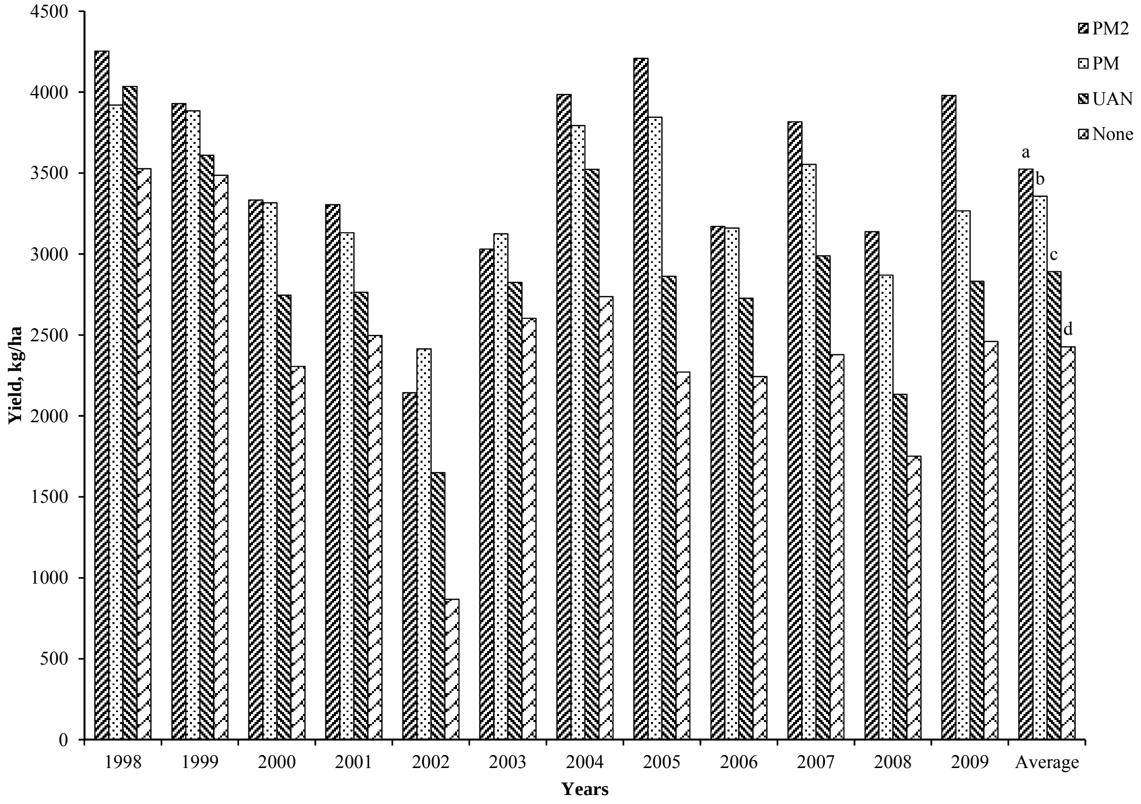

Figure 3.2 Average soybean yields as response to different types of N treatments over years

(Values having the same letter on top of the column are not significantly differences at α =0.05)

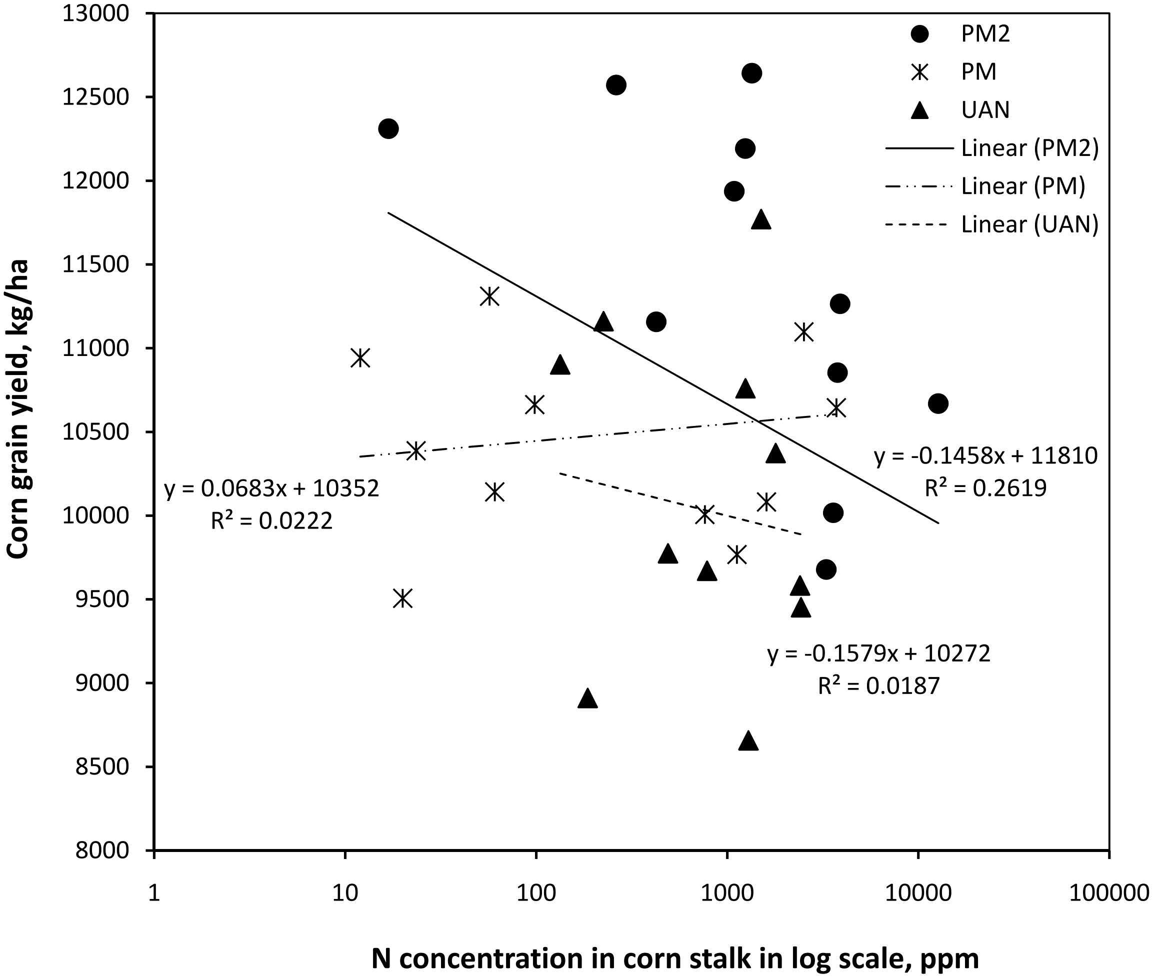

Figure 3.3 Correlation of corn grain yield and N uptake in corn stalk

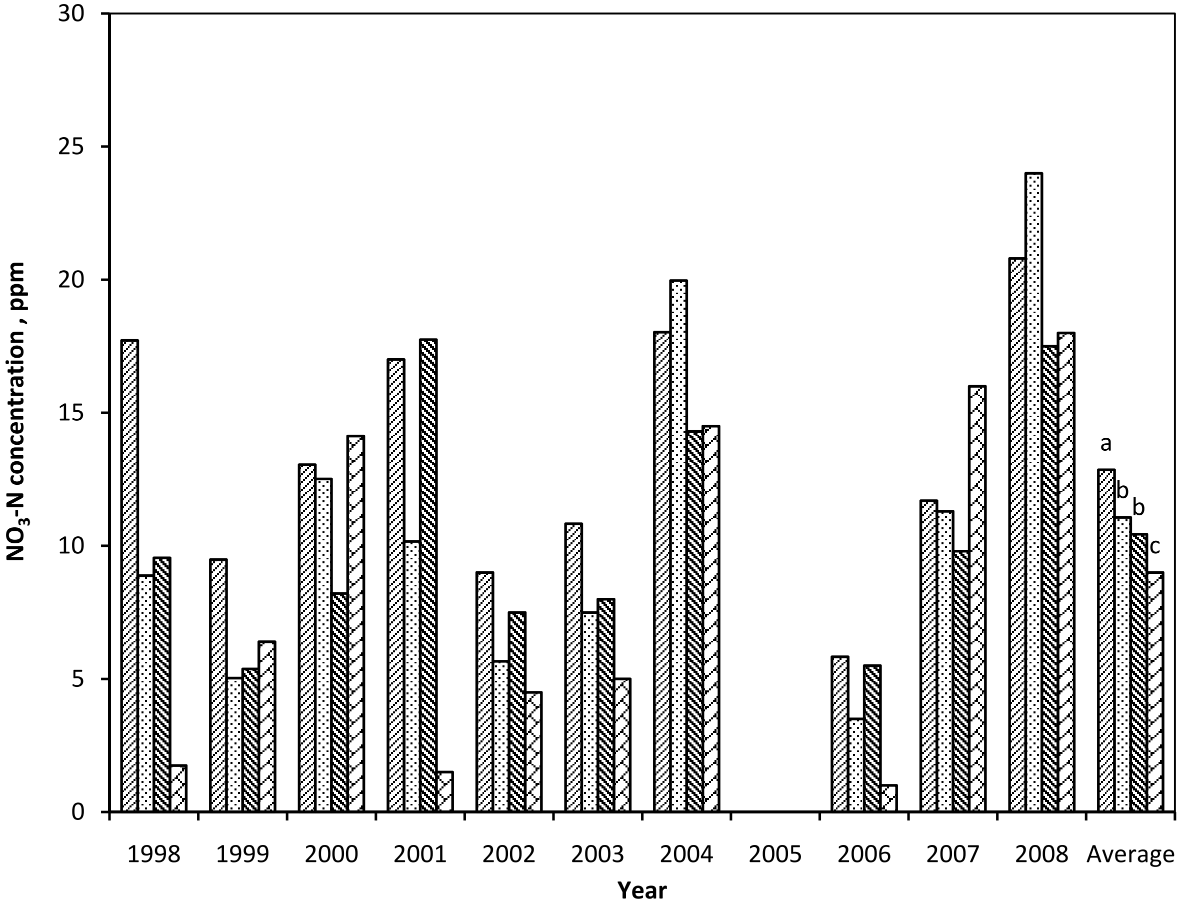

Figure 3.4 Average NO$_3$-N concentrations on top soil (0-30cm) as response to different N treatments over times

(Values having the same letter on top of the column are not significantly differences at α =0.05)

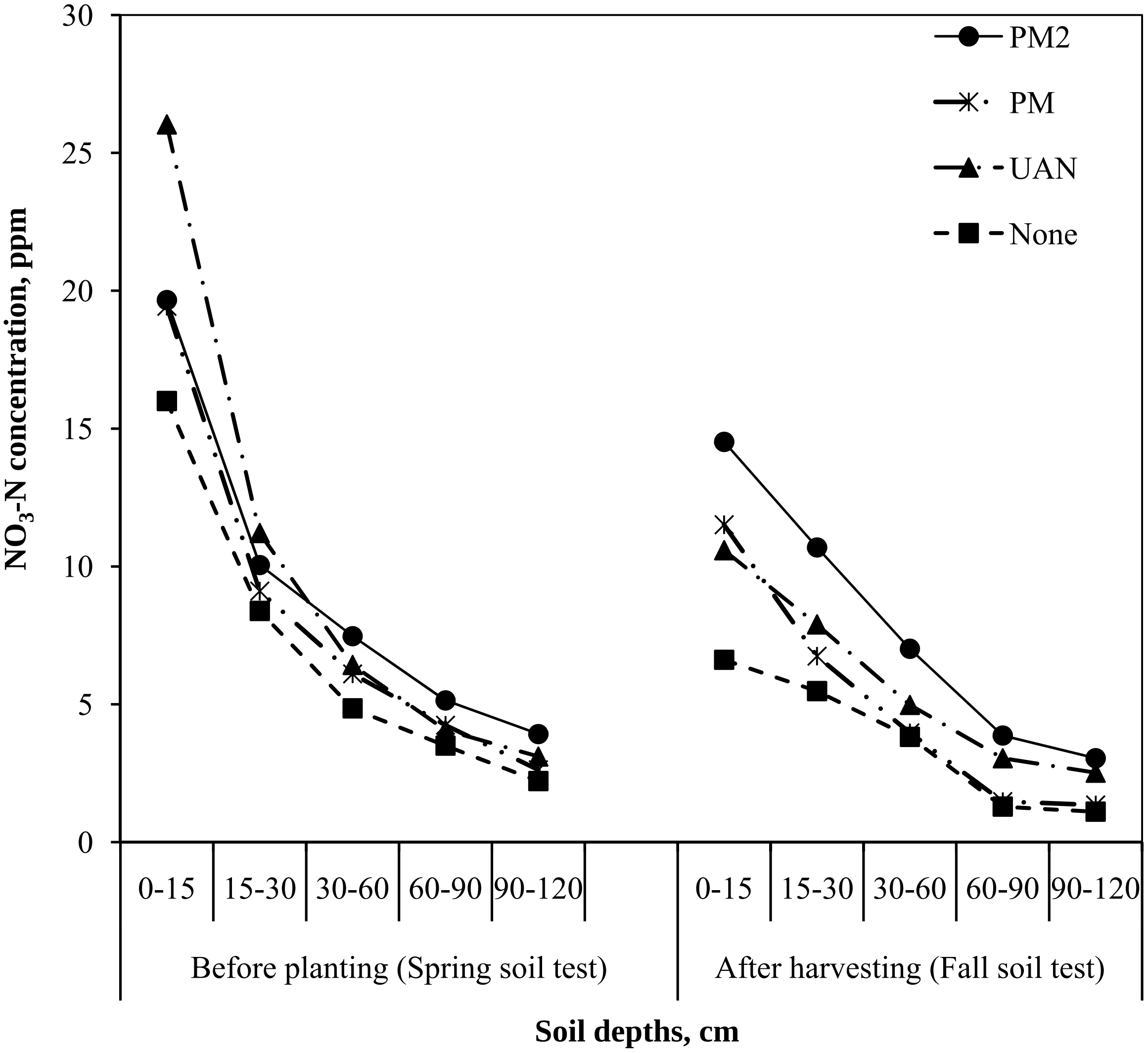

Figure 3.5 Comparisons of soil NO_3-N concentration as response to different N treatments and seasonal effects (Spring vs. Fall)

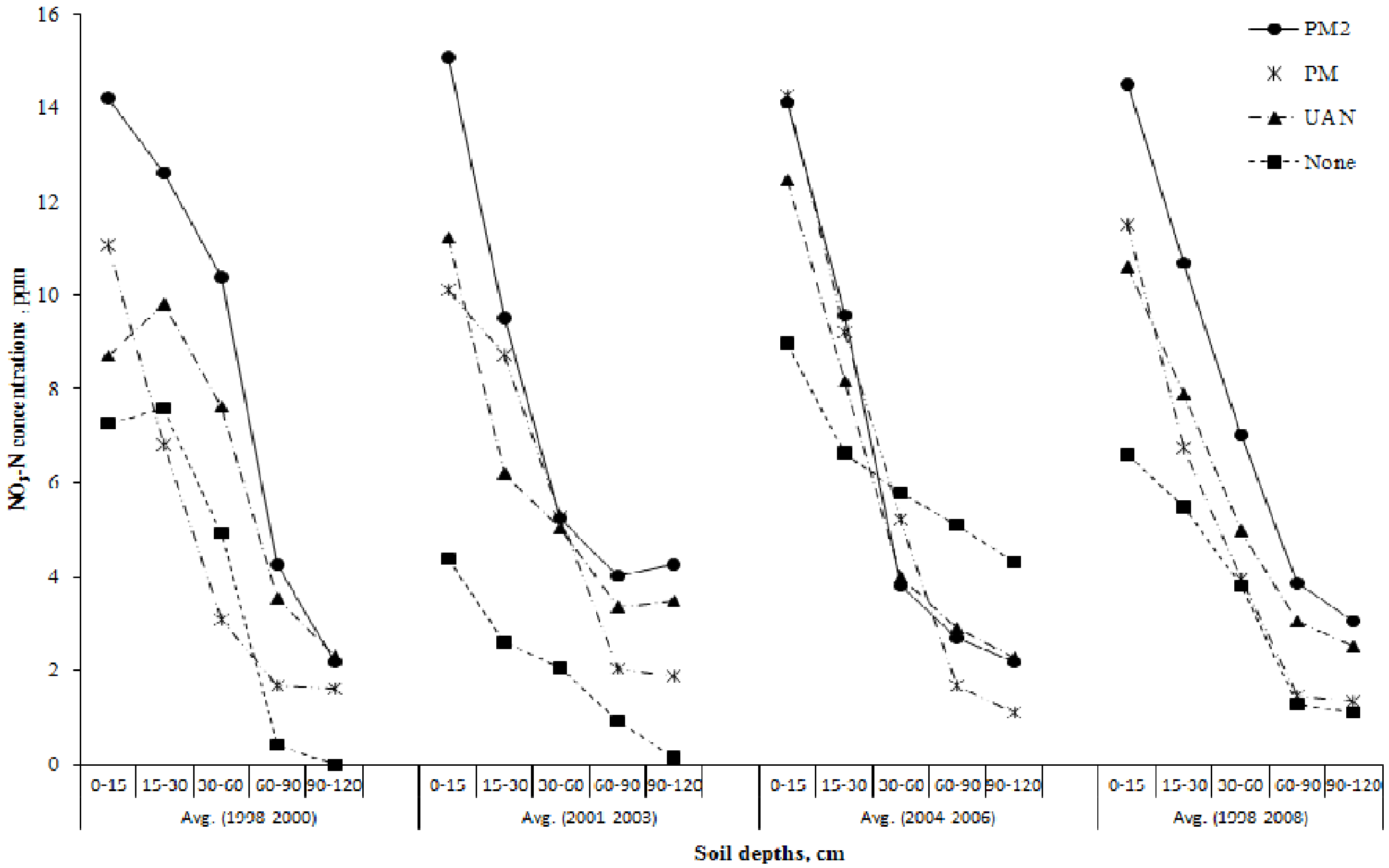

Figure 3.6 Long-term trends of NO_3-N concentrations in soil profiles as interaction effects of different N treatments, soil depths and times (1998-2008)

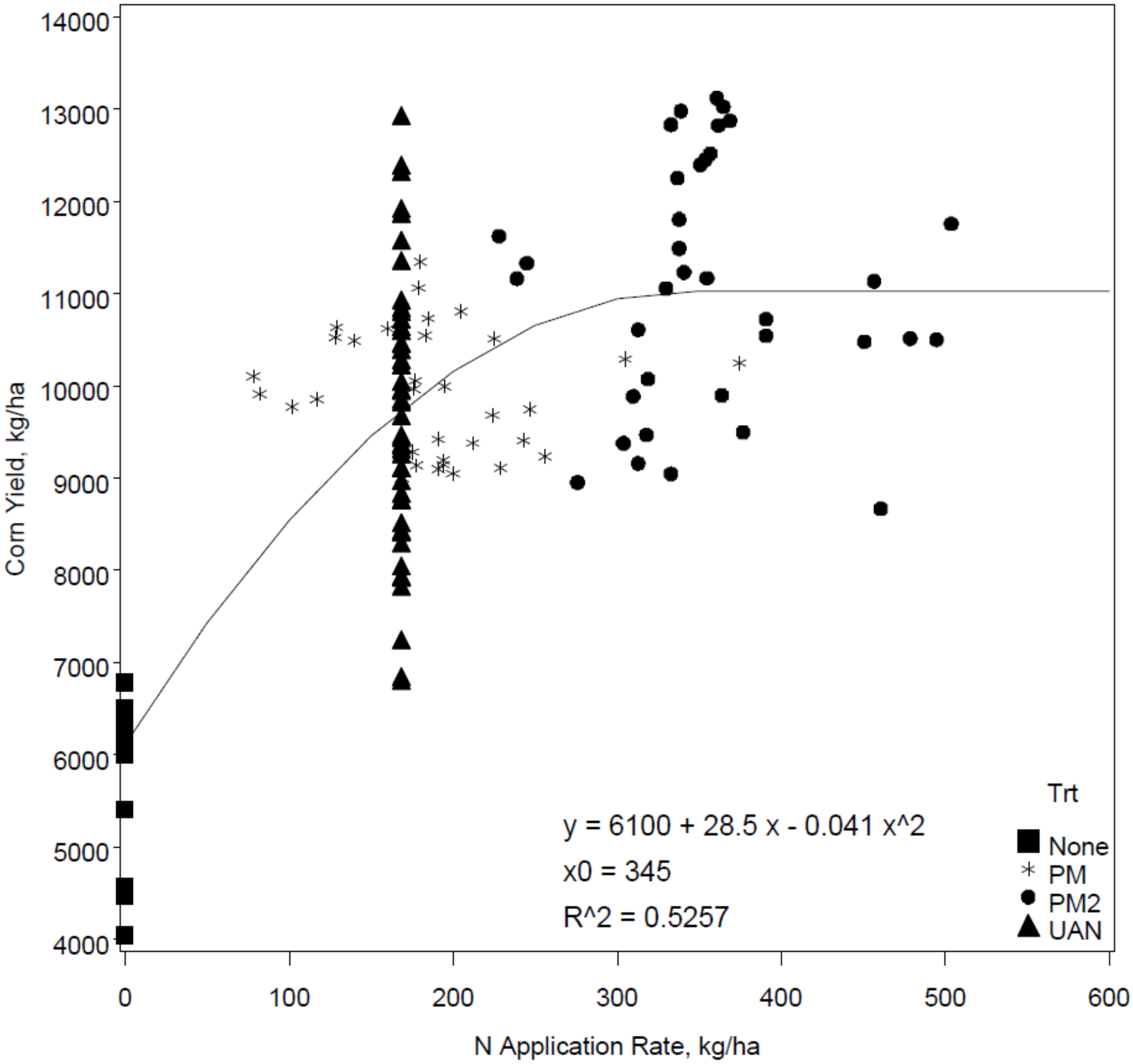

Figure 3.7 Correlation of corn yield and different N application rates

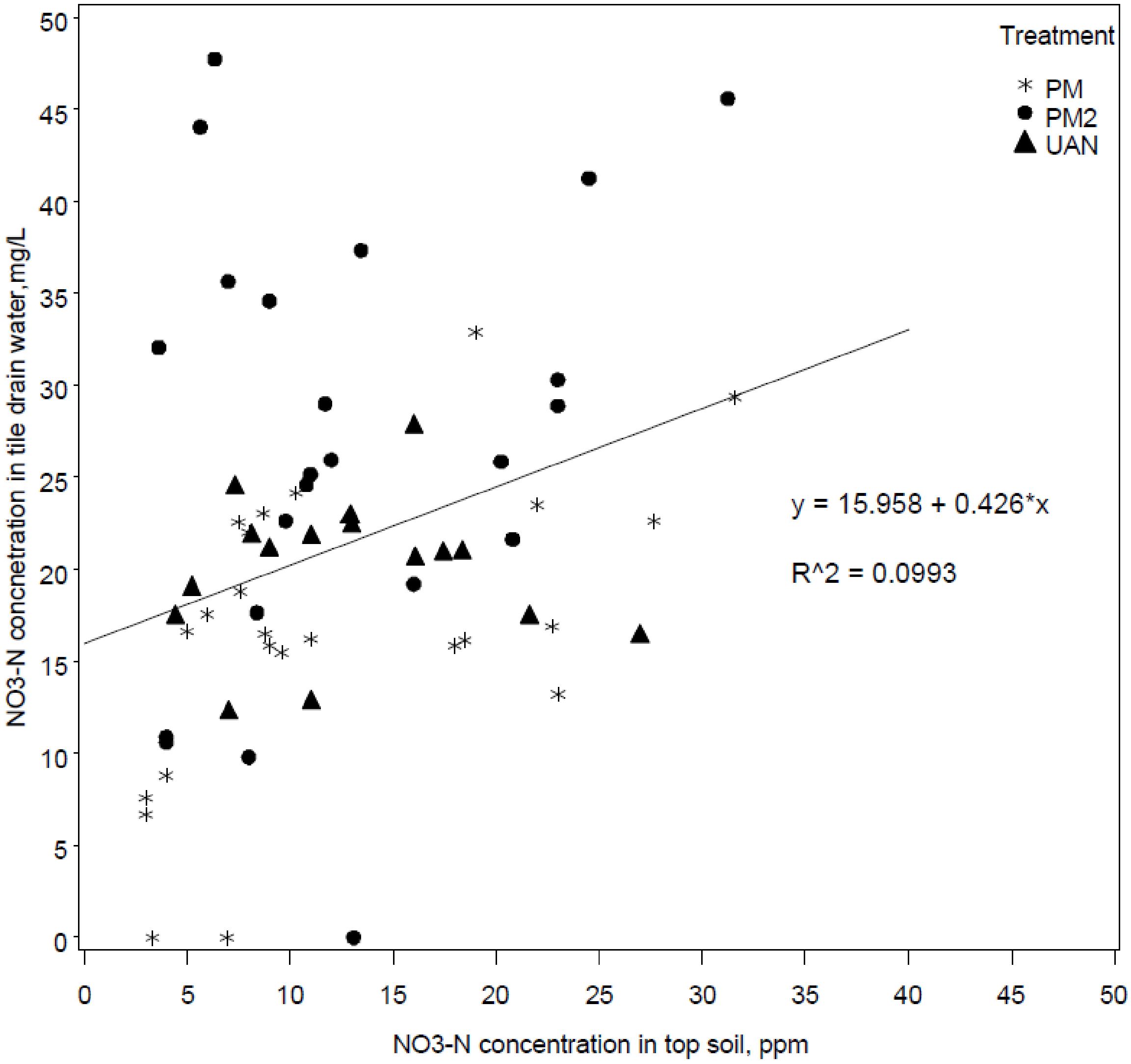

Figure 3.8 Correlation of NO_3-N concentrations in tile drain water and in top soil (0-30cm)

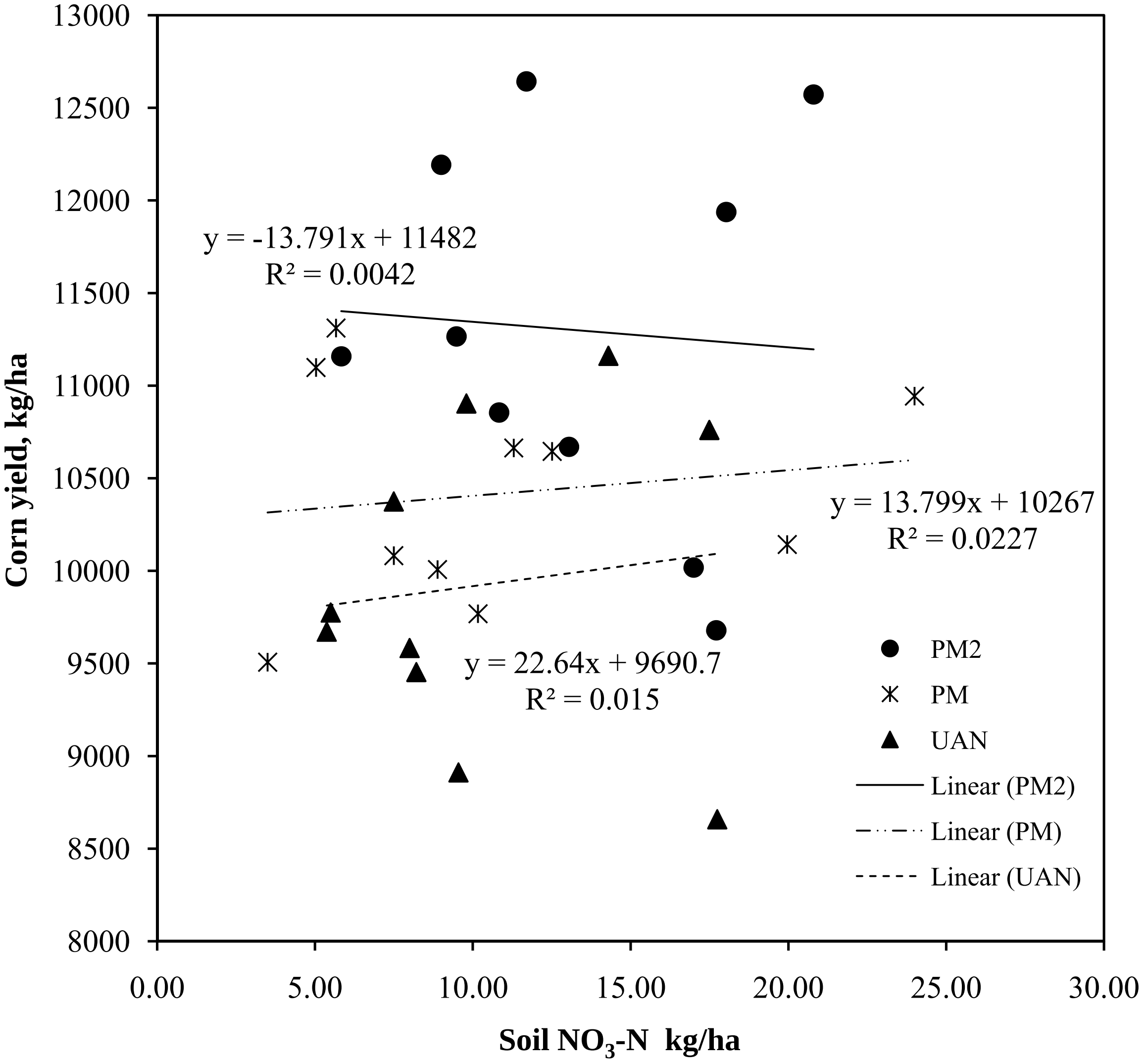

Figure 3.9 Correlation of corn yield and soil NO3-N concentration on top soil (0-30cm)

CHAPTER 4. PHOSPHORUS TRANSPORT IN SOIL AND TILE DRAIN WATER UNDER LONG-TERM APPLIED POULTRY MANURE

Huy Nguyen, Ramesh Kanwar, Philip Dixon, Jon Hobbs and Carl Pederson

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4.1 Abstract

Long-term surface land applied poultry manure on row crop production often increased the phosphorus concentration on top soil and may cause water quality concerns both in surface run-off and subsurface drainage leaching especially for fields having tile drain systems. Not much information on potential of phosphorus leaching in tile drain water is available on applying poultry manure on corn-soybean rotation under natural rain-fed condition with subsurface drainage systems. This study investigated the impacts of long-term surface applied poultry manure on crop production and P dynamic in soil and subsurface drainage water. Treatments include poultry manure at two application rates (168 kg-N/ha - PM and 336 kg-N/ha – PM2) with three replications for each rate, Urea Ammonium Nitrate – UAN (168 kg-N/ha) with four replications and a control (0 kg-N/ha). Eleven field plots having central tile drainage underneath the plot at the depth 150 cm. Corn is planted on one half of the plot and soybean on the other half. Only corn sides received the treatments. Corn and soybean rare rotated yearly. Water is sampling weekly and analyzed for PO_4-P concentration. Soil samples are collected in Spring and Fall on the corn side only at 5 different depths (0-15, 15-30, 30-60, 60-90, 90-120 cm) and analyzed for phosphorus using

Bray-P methods. The results showed that phosphorus concentration and losses in tile drain water are not significantly at monthly level among the treatments but overall, PM treatment gives lower PO_4-P concentration and losses than PM2 and UAN treatments. Soil PO_4-P residual concentrations are significantly higher from poultry manure treatments (PM2>PM>UAN=None) than others at two top soil levels (0-15 and 15-30 cm). The down gradient movements of PO_4-P from surface applied poultry manure to lower soil layer are not significant over long-term study. Analysis of long-term trends of top soil PO_4-P revealed that a positive linear trend of P built-up in top soil layers in PM2 and PM treatments but not on UAN and control treatments. However, the overall average of PO_4-P built up after 12 year study from PM treatment is still under the recommendation from P index of Iowa. It appears that applying poultry manure at lower rate (168 kg-N/ha) might be less causing P built-up issues over long-term especially when adding post soil P tests to monitor the soil PO_4-P residual concentration and combining with crop rotation systems.

Keywords: poultry manure, subsurface drainage, repeated measures, soil phosphorus, phosphorus leaching, corn-soybean rotation

Abbreviation: PM, poultry manure at 168 kg-N/ha; PM2, poultry manure at 336 kg-N/ha; UAN, urea ammonium nitrate (28% liquid) at 168 kg-N/ha.

4.2 Introduction

Poultry industry becomes more concentrated in Iowa and with that fast, steady growth, a large amount of poultry manure has been released yearly causing public concerns about the environmental impacts of poultry manure land disposal on crop production, soil and water quality. Historically, poultry manure has been utilized as land application in corn production to replace chemical fertilizer since it provides valuable nutrients for crop need such as N, P, K and other micro nutrients (Mg, Ca, Cu, Fe, Zn, etc.) (Edwards and Daniel, 1992; Sims and Wolf, 1994; Moore et al., 1995; Sims et al., 1998). With low water contain, poultry manure is often to be handled as dry form but when water contain increases, it causes challenges to have a uniform application as well as achieve desire application rates in practice. Unlike chemical fertilizer which has the right ratio of N: P: K that crop need, the ratio of N: P: K in poultry manure highly varies from facility to facility and from time to time dependent on many other uncontrollable factors (Robinson and Sharpley, 1995). In addition, the costs of transportation to move poultry manure from source facilities to the fields is major obstacle for the more efficient use of poultry manure (Moore et al. 1995; Sims and Wolf, 1994). As a result, exceeded application of poultry manure than crop removal is more likely happened and increases the risk of PO_4-P leaching to tile drain water, and/or built-up in soil profile after long time applied poultry manure both in pasture and crop fields (Sharpley et al. 1998; Sims et al. 1998; Turtola and Paajanen, 1995, Whalen and Chang, 2001). Eghball and Power (1999) compared the effects of N based vs. P based manure applications on corn production and soil phosphorus residual and found that not much difference of crop yield towards these two approaches but noticed a significant increase of soil residual P concentration after 4 years applied N based manure.

The transport of P in soil profile from poultry manure amended soils to surface waters may cause great environmental concerns such as eutrophication and impaired water quality. So far, the emphasis of most of the experiment have been mainly focused on erosion and surface runoff as the major processes for P export from poultry manure amended soils to surface water bodies (Sharpley, 1993; Sharpley et al., 1993; Daniel et al., 1994; Edwards et al., 1995; Hansen et al., 2002; Hodgkinson et al., 2002; Klatt et al., 2003, Adeli et al., 2005; and Kaiser et al., 2009). Consequently, the PO_4-P losses via leaching in tile drainage until recently, has rarely been considered as a significant transport process from poultry manure applied fields to surface waters (Sims et al., 1998).

While the effects of soil P built-up in top soil on P concentration in surface run-off from poultry manure treated plots have been documented in many previous studies (Edwards and Daniel, 1992; Sharpley et al., 1992; Edwards et al., 1995; Shreve et al., 1995; Sharpley, 1997; DeLaune et al., 2004; Harmel et al., 2009), not much direct PO_4-P leaching information, especially on surface applied poultry manure on crop production with subsurface drainage system, has been done to measure the PO_4-P leaching from poultry manure amended soils using continuous flow monitoring, and evaluate the effects of surface applied of poultry manure on PO_4-P leaching in subsurface drainage water because of the collection difficulty caused by weather variation, cost of automated sampling equipment and substantial land area requirement for poultry manure application (Nichols et al., 1994; Harmel et al., 2004). Several studies attempted to use the evidence of long-term P movement within soil profile as an indicator for PO_4-P leaching potential (Eghball et al. 1996; Mozaffari and Sims, 1996; Pote et al., 1996; McDowell et al., 2001; Maguire and Sims, 2002). For example, Kleinman et al. (2003) studied the relationship of phosphorus concentration in soil and in tile drain water under manure amended soils and reported that transport of P by subsurface pathways through preferential flow was significant mechanism to transfer PO_4-P from surface land applied manure to tile drain water. In another study, McDowell and Sharpley (2001) used the soil test phosphorus to predict the P concentration in tile drain waters and concluded that the concentrations of dissolved reactive phosphorus (DRP) concentration in surface runoff was significantly related to soil test phosphorus concentration in top soil (0-5 cm) and suggested to use of water and $CaCl_2$ extraction of surface soil P to estimate the P concentration in surface and subsurface runoff.

On an extended review of phosphorus loss in agricultural drainage, Sims et al. (1998) emphasized that the gradual, downward movement of PO_4-P in leaching water would posed the most environmental concern in water quality for long-term heavy surface applied manure soils having subsurface drainage system.

Therefore, we hypothesize that long-term repeated surface application of poultry manure at N-based rates on tile drained field plots may significantly elevate the PO_4-P residual concentration in soil profile, especially on top soil (0-30 cm) layers and consequently may result potentially high PO_4-P losses in surface run-off or leaching into tile drain water. The main objectives of the study are (1) to evaluate the long-term effects of poultry manure application rate (168 kg-N/ha and 336 kg-N/ha) on PO_4-P leaching in tile-drain water and the potential of P built-up in soil profile in compared with chemical fertilizer (UAN), and (2) to identify the trends of P built-up on top soil over time as response to different N treatment effects.

4.3 Materials and Methods

4.3.1 Field experimental set up

Field experiments were conducted from 1998 to 2009 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% (Table 4.1). Nicollet soils are characterized as moderately permeable, somewhat poorly drained, produce surface runoff, have high available water capacity, and seasonal high water table (Kanwar et al., 1999, Chinkuyu et al., 2002). Eleven field plots (with sizes varied from 0.19 ha to 0.47 ha) having the 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. 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) was planted on the other half of the same plot followed by the same procedure of crop rotation from the previous years (1998-2009). Fertilizer was applied only on corn side of each field plot. Poultry manure (PM) at two different rates (168 kg-N/ha and 336 kg-N/ha) and a chemical fertilizer (Urea Ammonium Nitrate – UAN, 28% liquid) at a rate of 168 kg-N/ha 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 0 kg-N/ha for comparison purposes. Corn and soybean residuals are left on the field using moldboard tillage which maintains at least 30% of crop residuals remained on the field.

4.3.2 Sample collection and analysis

Before manure application, three poultry manure samples were collected and sent to laboratory in Nevada, IA for analyzing the contents of N, P and K in order to determine the actual poultry manure application rates. The summary of poultry manure characteristics applied on field plots is presented in Table 4.3. Two water samples were collected weekly and/or after rainfall event (> 2 inches) on each field plot. After that, these samples were transferred to the Water Quality Laboratory of the Agricultural and Biosystems Engineering Department at Iowa State University for analyzing PO_4-P using a Lachat Model AE ion analyzer (Lachat Instrument, Milwaukee, WI). Tile flow volumes from each plot are collected weekly or daily based on the amount of rainfall occurred during that period. Three soil cores are collected at the corn side of field plot in Spring and Fall to evaluate the residual PO_4-P concentration in soil. The depth of soil core sampling is approximately 120 cm from the surface. Soil core then was divided into 5 different depths and composited into one sample to represent the PO_4-P concentration for that depth. Soil samples are analyzed for PO_4-P using Bray-P method.

4.3.3 Experimental design and statistical data analysis

Eleven field plots were used in this experiment with corn grown in one half of the plot and soybean grown on the other side. Rotation was done yearly for 12 years (1998-2009). Four fertilizer treatments including poultry manure (168 kg-N/ha and 336 kg-N/ha), UAN (168 kg-N/ha) and a control (0 kg-N/ha) were applied on the field plots (only on corn side). All the treatments were arranged in a completely randomized design with unbalance replications due to the lack of land for experiment.

Data from 12 years (1998-2009) of rainfall, tile flow, PO_4-P concentration and losses in tile drain waters were analyzed collectively with months within year as repeated measures.

Tile flow: The model for the square root of subsurface flow include treatment-specific cubic polynomials for the year, treatment-specific month effects (constant across years), a coefficient for monthly rainfall, and random effects for plots, months within years. Repeated measures covariance structures were examined for observations on the same plot in the same year. A compound symmetry structure gave the best AIC.

The mathematical model for tile flow:

$$Y_{ijk\ell} = \sqrt{\text{Tile flow (cm)}} \text{ for treatment } i, \text{ year } j, \text{ plot } k, \text{ month } \ell$$

$$Y_{ijk\ell} = \beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3 + \beta_4 x_{2j\ell} + \tau_{i\ell} + \alpha_{ik} + \gamma_{j\ell} + \varepsilon_{ijk\ell}$$

where:

$x_{1j} = \text{Year - 2003.5}$: Cyear

$x_{2j\ell} = \text{Precipitation (cm)}$: Monthly rainfall

$\alpha_{ik} \sim N(0, \sigma_\alpha^2)$: plot effect

$\gamma_{j\ell} \sim N(0, \sigma_\gamma^2)$: month within year

$\tau_{i\ell}$: treatment effects at specific month

$\beta_{0i} + \beta_{1i}x_{1j} + \beta_{2i}x_{1j}^2 + \beta_{2i}x_{1j}^3$: long-term trend

$\alpha_{ik} + \gamma_{j\ell} + \varepsilon_{ijk\ell}$: random effects

PO_4-P concentration and losses: The model for the natural logarithm of PO_4-P flow weighted concentration and losses include treatment-specific linear in time for the year, a coefficient for rainfall, and random effects for plots, months within years. Repeated measures covariance structures were examined for observations on the same plot in the same year. An autoregressive(1) structure gave the best AIC.

$Y_{ijk\ell} = \log \mathrm{PO_4\text{-}P}$ concentration (losses) for treatment i, year j, plot k, month ℓ

$$Y_{ijk} = \beta_{0i} + \beta_{1i}x_{1j} + \beta_4 x_{2j} + \alpha_{ik} + \gamma_j + \varepsilon_{ijk}$$

$x_{1j} =$ Year - 2003.5 : Cyear

$x_{2j} =$ Precipitation (cm): total yearly rainfall

$\alpha_{ik} \sim N(0, \sigma_\alpha^2)$: plot effect

$\gamma_j \sim N(0, \sigma_\gamma^2)$: year effects

$\varepsilon_{ijk} \sim N(0, \sigma_\varepsilon^2)$:error

Details of selection process to choose covariance structure for repeated measures analysis are found in Littell et al. (1998, 2006) and Piepho et al. (2004). Least square means of the fixed effects were computed, and the PDIFF option of the LSMEANS statement was used to display the differences among least square means for comparison. The LSMEAN values were used to compare treatment means and evaluate the treatment effects on tile flow, flow weighted phosphorus concentration and phosphorus losses in tile drains.

Data of soil phosphorus residual concentration (1998-2008) from all field plots are arranged as repeated measures in time (year and season) and space (depths). Data of Spring and Fall soil phosphorus are analyzed collectively but only the top soil $\mathrm{PO_4}$-P data (0 – 30 cm) after harvest in Fall are used to evaluate the long-term trend of potential $\mathrm{PO_4}$-P residual concentration built-up in top soil.

4.4 Results and Discussion

4.4.1 Poultry manure application rates and chemical analysis

Poultry manure is surface broadcasted on field plots using the manure applicator. Samples of poultry manure are collected and analyzed for N-P-K content before application. The averages of nutrient content from applied poultry manure over years are presented in Table 4.2. Based on the manure analysis, the actual application rates are made for both PM and PM2 treatments (Table 4.3). High fluctuation of moisture (ranging from 25% to 76%) and nitrogen content (ranging from 1.5% to 3.2%) in poultry manure over times also reflects the difficulty to handle poultry manure and to achieve the target N application rates (168 kg-N/ha and 336 kg-N/ha). On average, the actual application rates for PM2 and PM treatments are 354 kg-N/ha and 179 kg-N/ha, respectively. In some years, the actual rates are significantly lower or higher than the desired target rates (168 kg-N/ha and 336 kg-N/ha). Therefore, these yearly actual N application rates of poultry manure will be used in all statistical analysis and comparisons for other evaluations of impacts of poultry manure application rates on water and soil quality. The PM2 (336 kg-N/ha) and PM (168 kg-N/ha) treatment are still referred as high or low rates of poultry manure application in this study. Several previous studies on nutrient available from poultry manure noted that high availability of P (90-100%) in compared with that of N (40-55%) after first year applied. The slow N and P release from poultry manure to soil environment may possibly reduce nutrient losses in surface and subsurface runoff during early crop season (May-Jun) with often high precipitation. In addition, from the annual manure application rates of N and P to field plot, it showed that there is an unbalance and variable of N:P ratio from year to year between the

PM2 and PM treatment. On average, the actual applied N:P ratios from PM2 and PM treatments are 0.3:1 and 0.4:1 respectively. Overall, these results pointed out the difficulties at applying poultry manure nutrients at proper or desired rates, and the existence of significant uncertainties when using poultry manure, which may be higher than for chemical fertilizer in crop production (Mallarino and Sawyer, 2007). Thus, long-term study is needed to evaluate the possibility of P build up in soils to extremely high levels if poultry manure is applied at N – based rates especially for corn-soybean production.

4.4.2 Precipitation effects on tile flow, PO_4-P concentration and losses in subsurface drainage

Average rainfall distribution at the research site is presented in Table 4.4. Average precipitation during the growing season (May-Sep) is significantly lower than the drainage season (Mar-Oct) which is often observed in Midwest areas. Most of rainfall occurs in Apr-July which takes approximately 75% of total rainfall amount. The trend of precipitation in the month of May and June are higher than those of the normal trends at this experimental site. This may potentially cause the nutrient losses in tile drain water since corn is in early stage of development and not to consume the applied manure in May yet. Monthly tile flow from across the treatment as a function of rainfall distribution is presented in Table 4.5. The results showed that most of the tile flow occurred in April – July (taking 87% of the total annual tile flow) with the peak happened in month of May (46 mm). Most of the rainfall amount occurred after month of Jun are likely consumed by crop and little comes to the subsurface tile drain. The average of tile flow volume as response to total annual rainfall amount and different N treatments is presented in Figure 4.1. Yearly average comparisons among the treatments showed that subsurface flow is highest with the control treatment (256 mm) and lowest with PM treatment (99 mm). No significant difference between PM2 and UAN treatments ($p>0.05$). Tile flows were observed lowest on the year of 2000 as the drought year (rainfall: 426 mm) and highest on 2008 as the wet year (rainfall: 1074 mm). Statistical analysis showed that the trends of subsurface drainage flow are directly proportional with the monthly rainfall distribution ($p=0.034$) (Table 4.6). Also, the total rainfall amount has significant effects on the volume of tile flow ($p=0.0128$), PO_4-P concentration ($p= 0.047$) and PO_4-P losses ($p=0.0004$) in subsurface drainage in all N treatments. The tile flows from different treatments at monthly levels are statistically significant difference ($p= 0.0024$) which showed the highly variations of tile flow as response to monthly rainfall distribution.

4.4.3 Effects of poultry manure application on PO_4-P concentration and losses in tile drain waters

The annual average flow weighted phosphorus concentrations in tile drain water under different N treatments over times are presented in Figure 4.2. On average, the PO_4-P concentrations of PM2, PM, UAN and None are 15.1, 8.1, 9.6, and 9.2 μg/L, respectively. In most of the years, the PM2 treatments yield PO_4-P concentration exceeded the current standard (0.01 mg/L or 10 μg/L) for ortho-phosphate in tile drainage water (McDowell and Sharpley, 2004). However, statistical analysis showed that the differences among N treatments are not significant at both yearly and monthly levels (Table 4.6). It is likely that most of phosphorus is tied up in soil phase and little dissolved reactive phosphorus is present in tile drain waters, especially with the slow release of N and P from poultry manure. Also, the relationships of PO_4-P concentration in tile drain water and N-based (R^2=0.152) or P-based (R^2=0.0254) application rates (poultry manure) are not strongly correlated (Figure 4.3 and Figure 4.4). Therefore, it may conclude that the phosphorus concentration in tile drain water is not likely influenced by the poultry manure application rates in this study.

Average total PO_4-P losses in tile drain waters greatly varied from year to year (Figure 4.5). Highest losses of PO_4-P happened in wet year (1999) and lowest in drought year (2000). On average, the phosphorus losses of PM2, PM, UAN and None treatments are 15, 7, 11 and 16 g/ha, respectively. These amounts of PO_4-P losses are small in compared with those of NO_3-N losses in tile drain waters in this study. The first two years of the study (1998 and 1999), the losses of PO_4-P are relatively higher than those of the rest of 10 years ($p<0.001$). It may be due to the effects of preferential flow from new installed tile drainage and starting to apply poultry manure to the field plots. Statistical analysis for the trends of PO_4-P losses over years shows there is no significant change of phosphorus losses in tile drainage over times ($p=0.479$) and the differences among the treatments are also not significant difference ($p=0.178$). However, the rainfall showed highly significant impacts on phosphorus losses in tile drain waters ($p=0.004$). Also, the PO_4-P losses in tile drain waters are found strongly correlated to tile flow volume (R^2=0.74) (Figure 4.6) in which the increase of tile flow gives higher PO_4-P losses.

4.4.4 Effects of poultry manure on PO_4-P concentration in soil profiles

Soil phosphorus tests are conducted in corn side on each field plot in Spring (before applying manure) and in Fall (after harvesting) to evaluate the P residual in soil and the effectiveness of applied fertilizer. The averages of soil PO_4-P residual concentrations in soil profiles (0-120 cm) of Spring and Fall as a function of different N treatments and depths are presented in Figure 4.7. The results show that the increasing of soil P residual in top soil layers (0-15 cm) after harvesting over years with poultry manure treatments (PM2 and PM). There is a significant treatment*year*depth interaction for soil PO_4-P levels ($p=0.0296$) (Table 4.7). Also, the sharp decreasing trends of soil PO_4-P concentration over soil depths are found significantly in both Spring and Fall soil tests ($p<0.0001$). Statistical analyses show that the soil PO_4-P concentrations are not much significant differences of among the treatments at the depths greater than 30 cm ($p>0.05$) (Table 4.8). As presented in Figure 4.8, the correlation of dissolve phosphorus concentration in tile drain water and soil PO_4-P residual concentrations in top soil (0-30 cm) is found not significantly related ($p=0.165$ and $R^2=0.03$). These results clearly show the tendency of increasing soil PO_4-P residual in top soil layers and the slow downward movement of phosphorus in soil profiles from surface land applied poultry manure in this study.

The average soil PO_4-P residual concentrations in top soil (0-30 cm) over years as effects of different N treatments are presented in Figure 4.9. The results indicate that the PO_4-P concentrations of PM2 and PM treatments (58.5 and 44.8 ppm) have significantly higher than those of UAN and None treatments (17.0 and 14.6 ppm) on average. Table 4.9 presents the relationships of corn yield and top soil PO_4-P concentration (0-30 cm) over years. Statistical analysis shows that there is a strong correlation of soil P residual in top soil and corn yield ($p=0.001$). The interaction of seasonal effects of top soil PO_4-P concentrations and crop yield as response to different N treatments also suggests the directly proportional relationship of top soil P residual concentration (0-15 cm) with corn yield from different N treatments (Table 4.10). The differences of Spring and Fall soil P residual indicate that applying poultry manure at higher rates (336 kg-N/ha) may highly accelerate the P buildup in top soil with 55% increase in soil P residual concentration from post-harvest test in compared with 27% increases from PM treatment. It showed that applying poultry manure at lower rate (168 kg-N) gives comparable corn yield to both PM2 and UAN treatments and not much elevation of soil P buildup in top soil layers (0-30 cm).

4.4.5 Long-term trends of soil PO_4-P residual concentration as a response to repeated poultry manure application

Statistical analyses for soil PO_4-P concentration from all N treatments over five different depths and years showed a significant treatments*years*depth interaction ($p=0.029$). Thus, we conduct the estimates and comparisons of average of three periods during the 11 years study (1998-2009) to test the hypothesis that long-term applied poultry manure may elevate the PO_4-P residual concentration in soil profiles (0-120 cm). The results showed that the trends of soil PO_4-P residual concentration are similar across all N treatments (poultry manure, UAN and control) over years (Figure 4.10). Soil phosphorus concentrations are found highest on top soil level (0-15 cm) and sharply decreasing at lower depths. Below the depth of 30 cm, the phosphorus concentrations from all treatments are very small and not statistically significant differences from each other. Further analysis of the trends of phosphorus build up on top soil (0-30 cm) as illustrated in Figure 4.11 confirm the significantly fast elevation of soil phosphorus residual from poultry manure treatments (PM2 and PM) in comparison to those of UAN and Control treatments. Between PM2 and PM treatments, the results suggest that applying poultry manure at lower rates (168 kg-N/ha) gives lower soil phosphorus residual concentration after harvesting and may reduce the environmental concerns associated with exporting P from agriculture fields to surface water bodies nearby.

4.5 Conclusions

The long-term field study (1998-2009) aimed to evaluate the environmental impacts of poultry manure surface application on phosphorus leaching in subsurface drainage, soil P residual in top soil and P movement in soil profiles under a corn-soybean rotation system in Iowa. The treatments include two application rates of poultry manure (168 kg-N/ha and 336 kg-N/ha) with three replications, one chemical fertilizer rate (168 kg-N/ha) of Urea Ammonium Nitrate (28% liquid) with four replications and a control (0 kg-N/ha) with one replication. The treatments are randomly assigned on eleven field plots (0.1 ÷ 0.4 ha) having a single central subsurface tile drainage at the depth approximately 1.5 m of the plot. Corn is planted on one half and soybean is on the other half of the field plot. Corn and soybean are rotated yearly. Only corn side is received the treatment. Tile water samples are collected and analyzed for PO_4-P. Three soil cores are taken from each field plot in Spring (before applying manure) and Fall (after harvesting) at the depth 120 cm and divided into 5 different depth corresponding to 5 soil layers (0-15, 15-30, 30-60, 60, 90 and 90-120 cm). Soil samples are analyzed for PO_4-P using Bray-1 P method. Following conclusion may be drawn from the results from 12 years study:

1. Phosphorus leaching from poultry manure application to subsurface drainage is proportionally to the tile flow and significantly impacted by the rainfall amount and distribution. On average, the PM treatment (168 kg-N/ha) gives lower PO_4-P concentration than 0.01 mg/L across all years. Applying poultry manure at higher

rates (PM2 treatment at 336 kg-N/ha) results the PO_4-P concentration in tile drain water exceeded the US-EPA standard (0.01 mg/L) under this corn-soybean rotation system.

2. Most P is buildup on top soil profile (0-30 cm) in all treatments. At lower depth, there is no significantly difference of soil P concentration among the treatment. Thus, we did not observe the downward movement of P in soil profile under long-term poultry manure application in this study.
3. Soil phosphorus residual (0-30 cm) from poultry manure treatments are significantly higher than those of chemical fertilizer and control over long-term application. The increasing trends of top soil P buildup from both poultry manure application rates are observed. Overall, applying poultry manure at 336 kg-N/ha caused faster and higher PO_4-P buildup in top soil than at 168 kg-N/ha with average of soil PO_4-P residual concentration of 131 kg/ha vs. 100 kg/ha, respectively. Thus, it is likely that applying poultry manure at lower rates (168 kg-N/ha) under this corn-soybean rotation system may still be able to maintain the soil productive and mitigate the environmental concerns from soil P buildup in top soil layers to surface and subsurface water quality over long-term.
4. The results from this long-term study confirm that the relationship of soil P test in top soil (0-15 cm) and phosphorus concentration in tile drainage water are not significantly correlated for Nicollet loamy soils in Iowa having subsurface drainage systems as previous studies pointed out. However, the strong correlation of subsurface tile flow and phosphorus losses in tile drain water suggested that there is a potential nutrient loss in subsurface runoff in case the appropriate Best

Management Practices (BMPs) are not applied properly to avoid the preferential flow which creates a direct pathway from surface soil to tile drain.

4.6 References

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Table 4.1 Soil characteristics of Nicollet loamy soil at the research site (Field 5A)

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	Bulk density (mg/m^3)	Organic matter (%)
15	31.3	43.6	25.1	7.3	1.20	4.3
30	31.2	42.8	26.0	6.7	1.30	4.0
60	27.7	42.2	30.1	6.9	1.35	2.9

*Adapted from Chinkuyu et al. (2002)

Table 4.2 Average chemical analyses of poultry manure characteristics applied in field plots

Year	**% as TKN**	**% as Ammonia N**	**% as K_2O**	**% as P_2O_5**	**% H_2O**
1998	1.5	1.1	1.3	1.0	47.5
1999	3.0	0.8	2.1	4.3	49.8
2000	3.2	0.8	2.3	3.9	32.4
2001	2.2	1.6	2.0	2.7	57.0
2002	1.6	0.7	0.6	1.1	53.7
2003	1.9	0.9	1.1	1.4	74.6
2004	2.4	1.6	1.1	2.1	69.9
2005	2.1	0.2	3.1	6.1	25.0
2006	2.0	1.0	1.2	2.6	58.4
2007	1.8	1.0	1.4	1.0	76.3
2008	2.2	.	1.1	2.0	59.1
2009	2.7	0.7	1.7	1.9	58.4
Average	2.2	0.9	1.6	2.5	55.2
Std. Error	0.1	0.1	0.4	0.2	0.4

Table 4.3 Average poultry manure N and P application rates on field plots over times

	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	10632	160	108	153	23163	352	220	300
1999	9866	301	439	230	14953	446	630	278
2000	3254	87	128	79	8872	331	333	199
2001	9013	195	245	181	15318	331	416	308
2002	8063	132	87	49	14468	237	156	88
2003	11565	124	159	123	18636	345	255	198
2004	10364	249	218	117	20006	480	420	226
2005	8871	186	541	278	16725	351	1020	525
2006	9703	195	247	115	17000	342	434	201
2007	9632	171	95	133	19542	346	194	270
2008	8059	164	250	91	15872	324	232	179
2009	6591	180	124	232	13312	363	250	115
Average	8801	179	220	148	16489	354	380	241
Std. Error	633	16	41	20	1057	17	70	32

Table 4.4 Precipitation at research site during the study period (1998-2009)

	Month								Growing Season (May-Sep)	Drainage Season (Mar-Oct)
Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		
					(mm)					
1998	71	81	92	274	68	94	24	102	552	806
1999	25	207	150	185	162	151	61	9	709	949
2000	11	21	120	104	72	34	26	50	356	437
2001	28	96	190	50	48	74	149	65	511	700
2002	10	95	130	81	150	209	38	79	606	790
2003	29	112	122	150	168	25	100	24	565	730
2004	96	61	208	91	50	132	34	45	515	717
2005	35	82	111	124	104	172	111	9	622	748
2006	74	109	55	21	141	156	191	63	564	811
2007	81	153	169	52	75	200	48	137	545	915
2008	71	130	216	271	234	53	78	92	852	1145
2009	103	116	102	104	70	123	24	186	424	829
Average	53	105	139	125	112	119	74	72	568	798
Normal	54	89	108	129	106	102	87	65	532	740

Table 4.5 Average tile flow volume (mm) over all treatments by year and month

Year	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1998	2	33	31	96	41	0	0	0	203
1999	0	44	46	55	6	3	0	0	154
2000	0	0	1	4	0	0	0	0	5
2001	0	3	41	22	2	0	0	0	69
2002	0	0	46	19	10	6	0	0	81
2003	0	0	84	10	46	0	0	0	141
2004	15	47	39	52	1	0	0	0	153
2005	0	24	42	10	7	9	0	0	93
2006	0	23	52	3	1	0	72	75	226
2007	0	0	14	59	10	0	0	0	83
2008	0	63	77	167	50	48	0	0	405
2009	0	51	83	27	3	0	0	10	174
Average	1	24	46	44	15	6	6	7	149

Table 4.6 ANOVA for tile flow, PO_4-P concentration and losses in subsurface drainage (1998-2009)

Effect	Num df	Den df	F value	Pr > F
Tile flow	----------	----------	----------	----------
Rain	1	310	6.27	0.0128
Treatment	3	5	2.03	0.2279
Cyear	1	310	1.66	0.1985
Cyear2	1	310	10.02	0.0017
Cyear3	1	310	6.45	0.0116
Cyear*Treatment	3	310	1.26	0.2869
Cyear2*Treatment	3	310	1.04	0.3744
Cyear3*Treatment	3	310	0.70	0.5550
Month	7	44	2.43	0.0340
Month*Treatment	21	310	2.17	0.0024
PO_4-P concentration	----------	----------	----------	----------
Rain	1	296	3.97	0.0472
Treatment	3	5	1.66	0.2887
Cyear	1	296	0.09	0.7692
Cyear*Treatment	3	296	1.72	0.1639
Month	6	40	1.77	0.1305
Month*Treatment	18	296	0.86	0.6280
PO_4-P losses	----------	----------	----------	----------
Rain	1	280	12.91	0.0004
Treatment	3	5	2.49	0.1748
Cyear	1	280	0.50	0.4791
Cyear*Treatment	3	280	2.19	0.0895
Month	6	40	2.37	0.0470
Month*Treatment	18	280	0.68	0.8303

Table 4.7 ANOVA for soil PO_4-P concentration in soil profiles (1998-2006)

Effects	**Num df**	**Den df**	**F value**	**Pr > F**
Treatment	3	7	1.31	0.3437
Depth	4	658	554.65	<0.0001
Treatment*depth	12	658	11.31	<0.001
Year	7	658	1.03	0.4051
Treatment*year	21	658	1.25	0.2017
Year*depth	28	658	2.00	0.0018
Treatment*year*depth	84	658	1.34	0.0296

Table 4.8 Selected estimates for comparisons soil PO_4-P concentrations in five different soil depths

Soil depths (cm)	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**
Labels	---------------------------------- Pr > |t| ----------------------------------				
PM2 vs UAN	<0.0001	<0.0001	> 0.05	> 0.05	> 0.05
PM vs UAN	<0.0001	<0.0001	> 0.05	> 0.05	> 0.05
PM vs PM2	<0.0001	0.294	> 0.05	> 0.05	> 0.05
None vs PM	0.0022	0.0147	> 0.05	> 0.05	> 0.05
None vs PM2	<0.0001	<0.0001	0.0304	> 0.05	> 0.05
None vs UAN	<0.05	0.126	> 0.05	> 0.05	> 0.05

Table 4.9 Interactions of corn yield and Fall soil PO_4-P concentrations in top soil (0-30 cm) from field plots under different N treatments over times

	Average corn yield				Top soil PO_4-P concentration (0-30cm)*			
Treatment	**PM2**	**PM**	**UAN**	**None**	**PM2**	**PM**	**UAN**	**None**
Year	--------------------kg/ha -------------------				-------------------- ppm ---------------------			
1998	9678	10007	8911	4326	47.8	34.8	17.8	13.3
1999	11265	11098	9671	5783	36.8	34.8	25.0	24.5
2000	10669	10645	9453	6971	38.7	48.7	10.0	29.5
2001	10017	9768	8658	6629	36.2	23.8	17.9	6.5
2002	12192	11311	10374	4894	67.5	34.7	19.3	16.0
2003	10854	10082	9583	6759	39.8	34.0	11.0	11.0
2004	11937	10142	11161	6423	72.0	43.3	17.9	10.3
2005	12311	10388	11771	6263	--	--	--	--
2006	11158	9506	9775	6325	88.8	58.8	24.8	9.5
2007	12643	10663	10903	6780	84.3	77.0	14.5	9.0
2008	12572	10943	10760	4315	73.3	58.5	12.0	16.5
2009	12733	10244	9759	6374	--	--	--	--
Average. ‡	11,502^a	10,400^b	10,065^b	5,987^c	58.5^a	44.8^b	17.0^c	14.6^c

* Fall soil PO_4-P test results are available for ten years (1998-2004 and 2006-2008)
‡ Values in the same row followed by the same letter were not significantly different at significant level $\alpha = 0.05$. Data of corn yield and top soil PO_4-P concentration are analyzed separately.

Table 4.10 Interaction of top soil PO_4-P concentrations and corn yield as response to different N treatments with seasonal effects (Spring and Fall)

		Soil sample depth in cm			
		Before planting (Spring)*		After harvesting (Fall)**	
N applied rates	Corn yield‡	0-15	15-30	0-15	15-30
kg/ha	kg/ha	------------------------------ PO_4-P, ppm ------------------------			
PM2 (336)	11,502^{a}	66.9	14.1^{a}	103.5^{a}	13.5^{a}
PM (168)	10,400^{b}	60.0^{b}	11.2^{b}	75.9^{b}	13.9^{a}
UAN (168)	10,065^{b}	33.4^{c}	12.8^{b}	27.7^{c}	8.6^{b}
None (0)	5,987^{c}	20.8^{d}	6.7^{c}	23.1^{d}	6.4^{bc}

*Spring soil test is stopped collecting in 2005. Data of years 2007 and 2008 are excluded in this table.

**Fall soil test results are available for ten years (1998-2004 and 2006-2008)

‡ Values in the same column followed by the same letter were not significantly different at significant level α = 0.05.

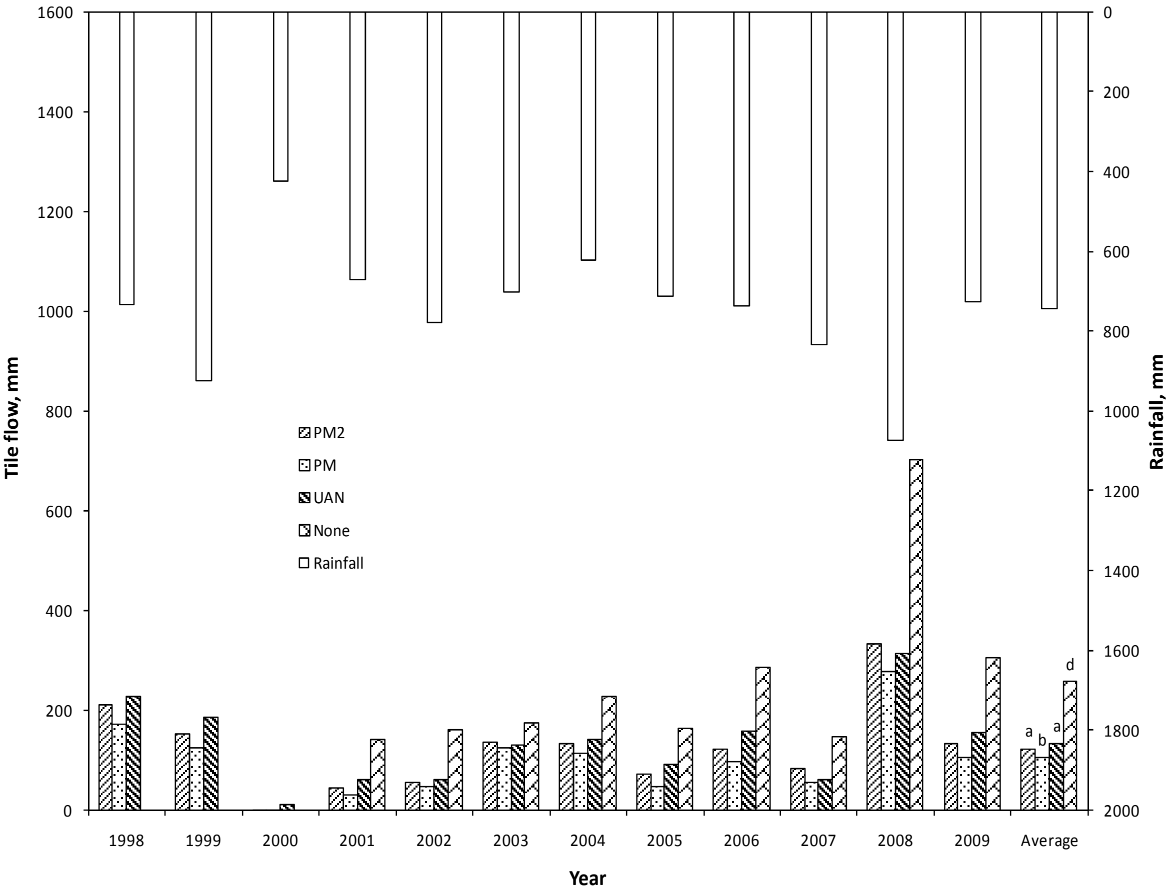

Figure 4.1 Subsurface drainage flow and precipitation over times as effects of different N treatments

(Values followed by the same letters are not significantly different at α=0.05)

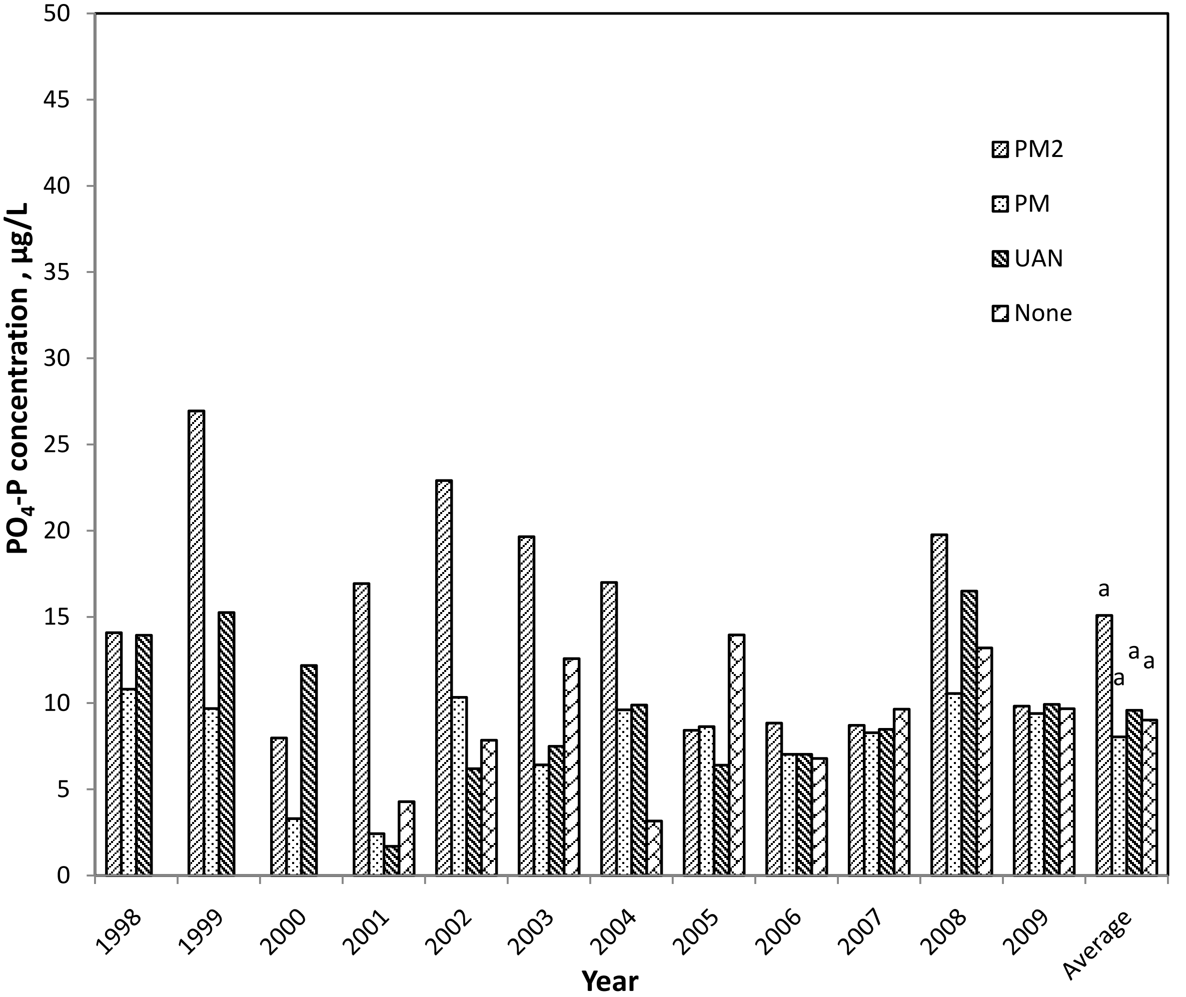

Figure 4.2 Average flow weighted PO$_4$-P concentration tin tile drainage water as effects of different N treatments over times

(Values followed by the same letters are not significantly different at α=0.05)

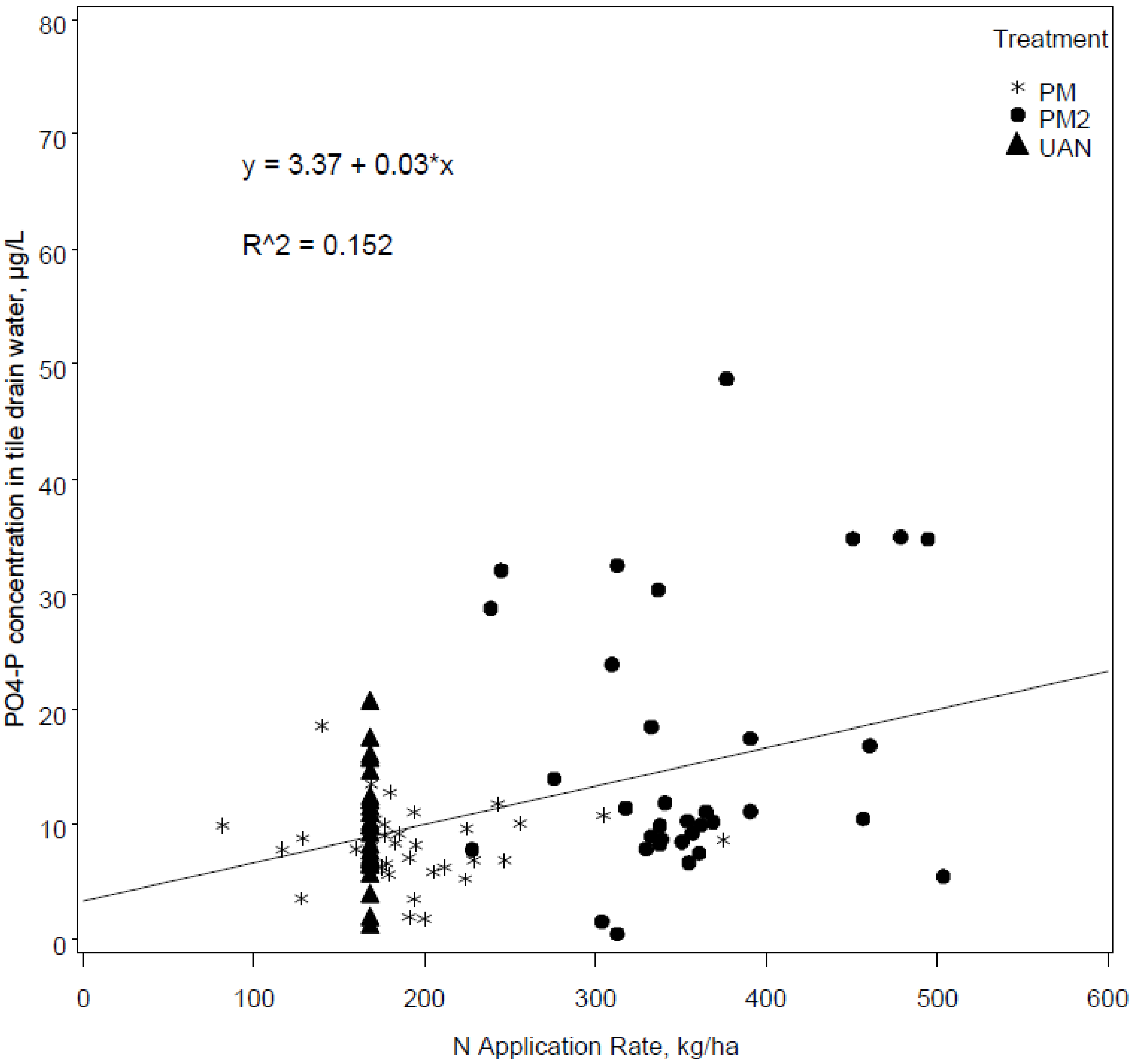

Figure 4.3 Correlation of PO_4-P concentrations in tile drain water and different N application rates

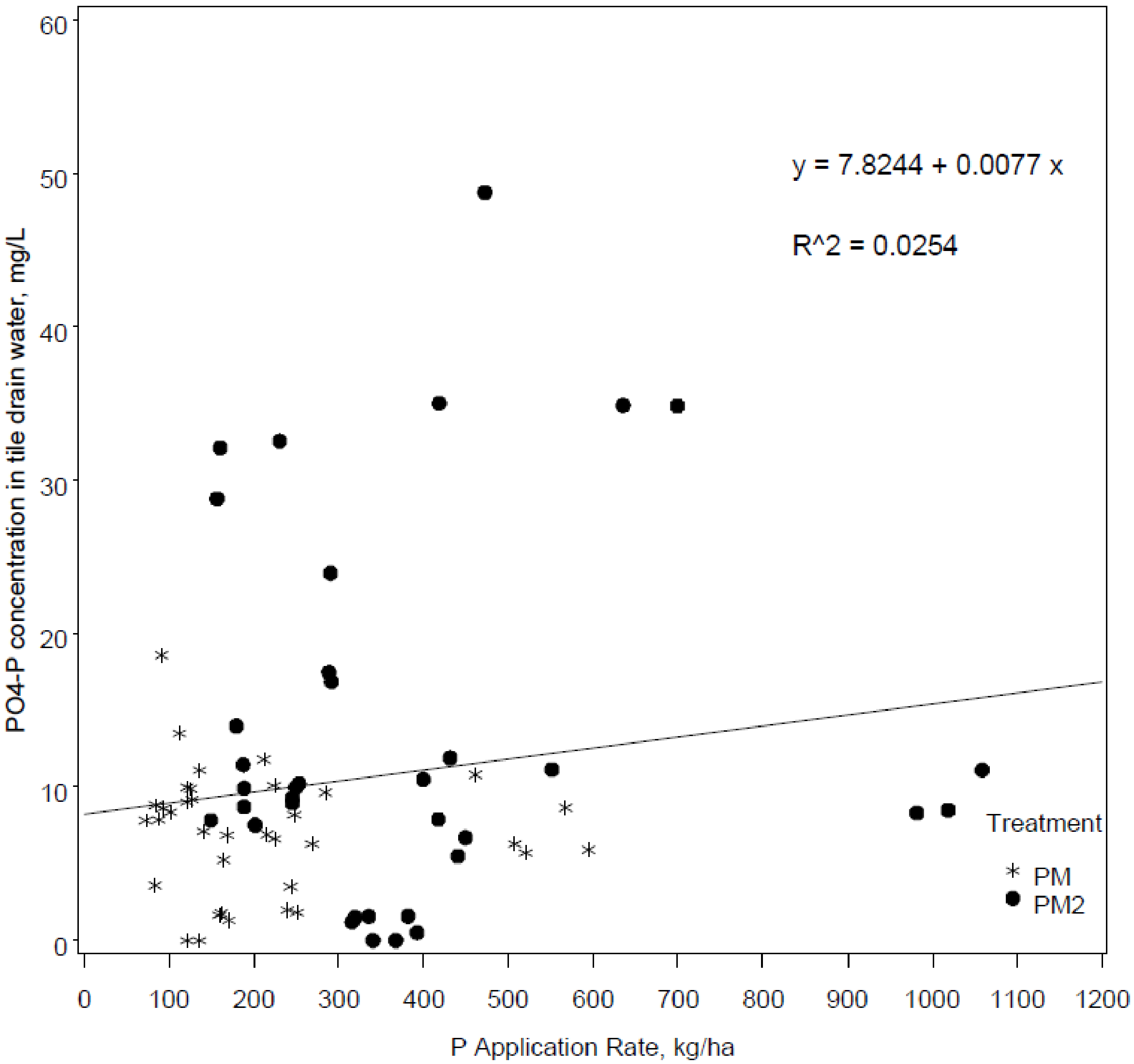

Figure 4.4 Correlation of PO_4-P concentrations in tile drain water with P application rates

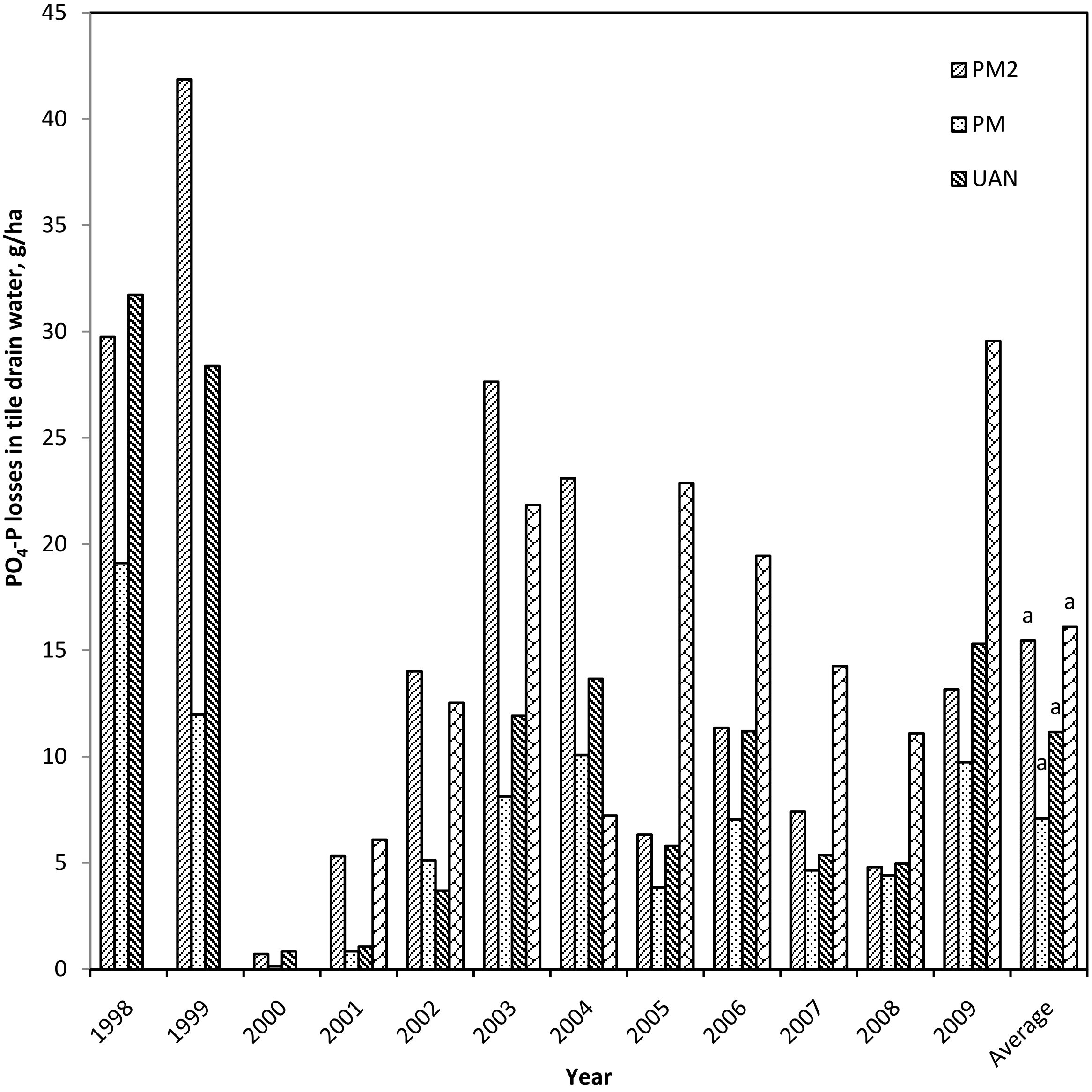

Figure 4.5 Average PO$_4$-P losses in tile drain water as effects of different N treatments over times

(Values followed by the same letters are not significantly different at α=0.05)

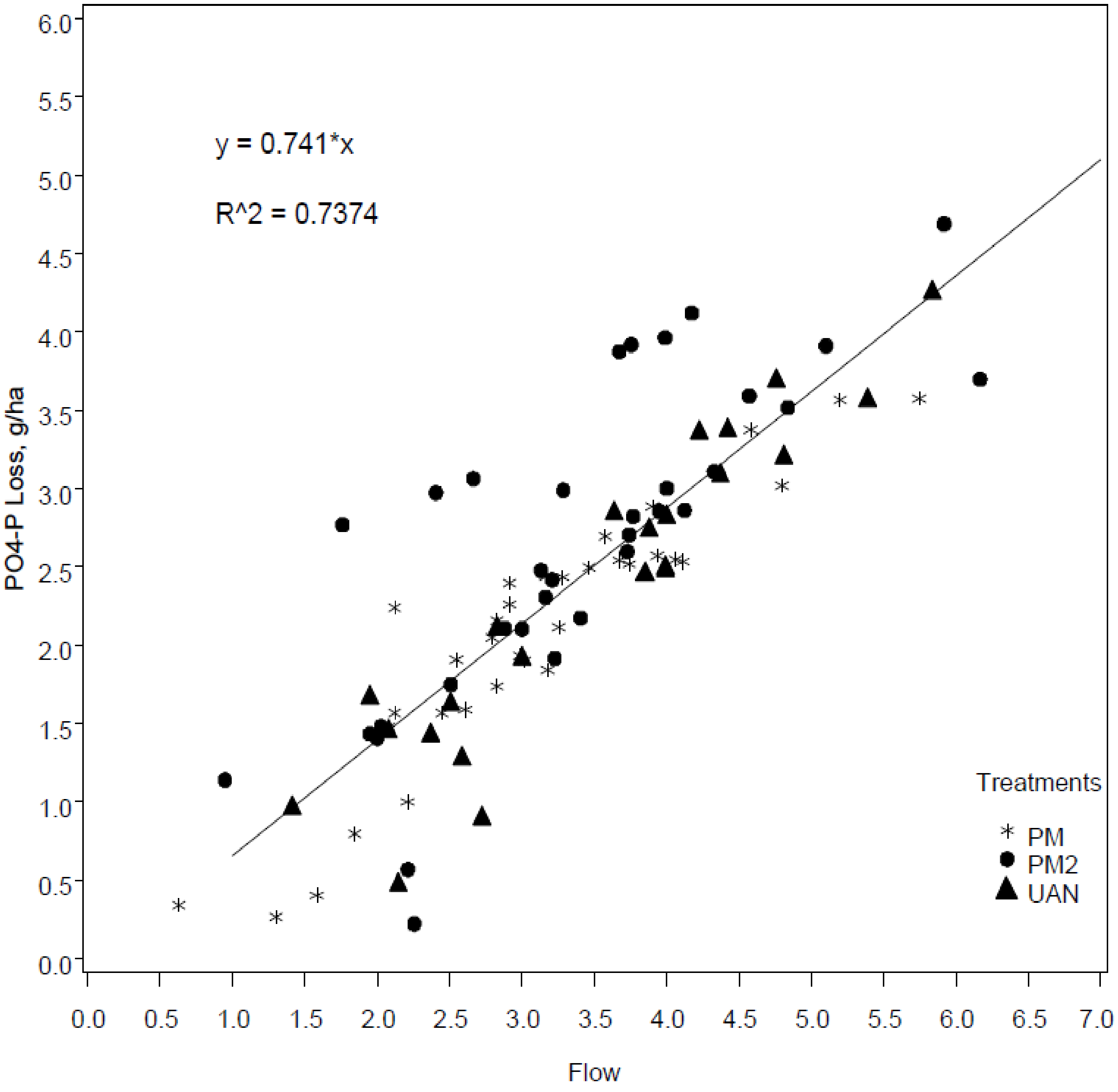

Figure 4.6 Correlation of tile flow (mm) and PO_4-P losses (g/ha) in tile drain water

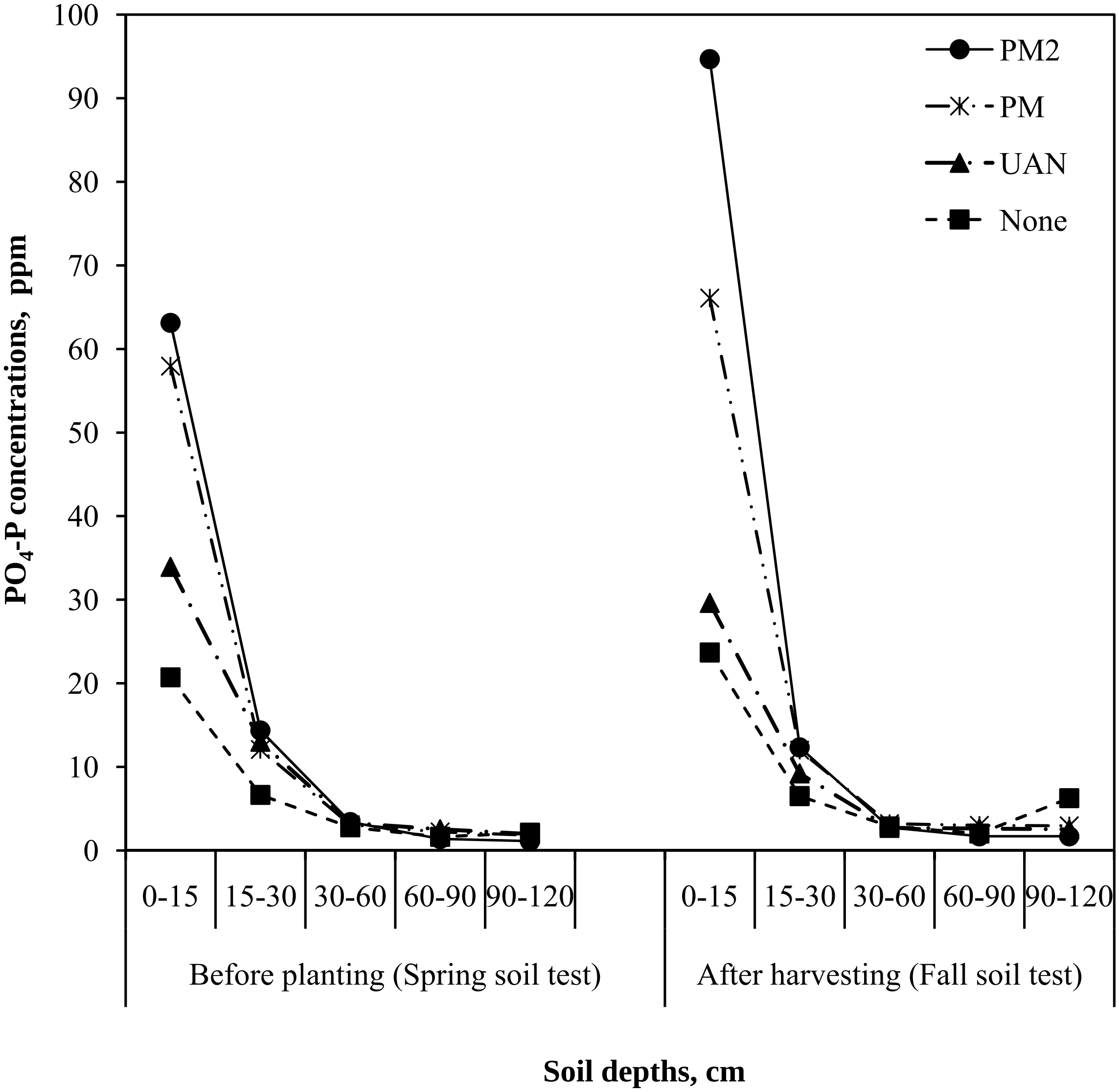

Figure 4.7 Interaction effects of soil depth, N treatments, seasonal effects on PO$_4$-P concentrations in soil profiles

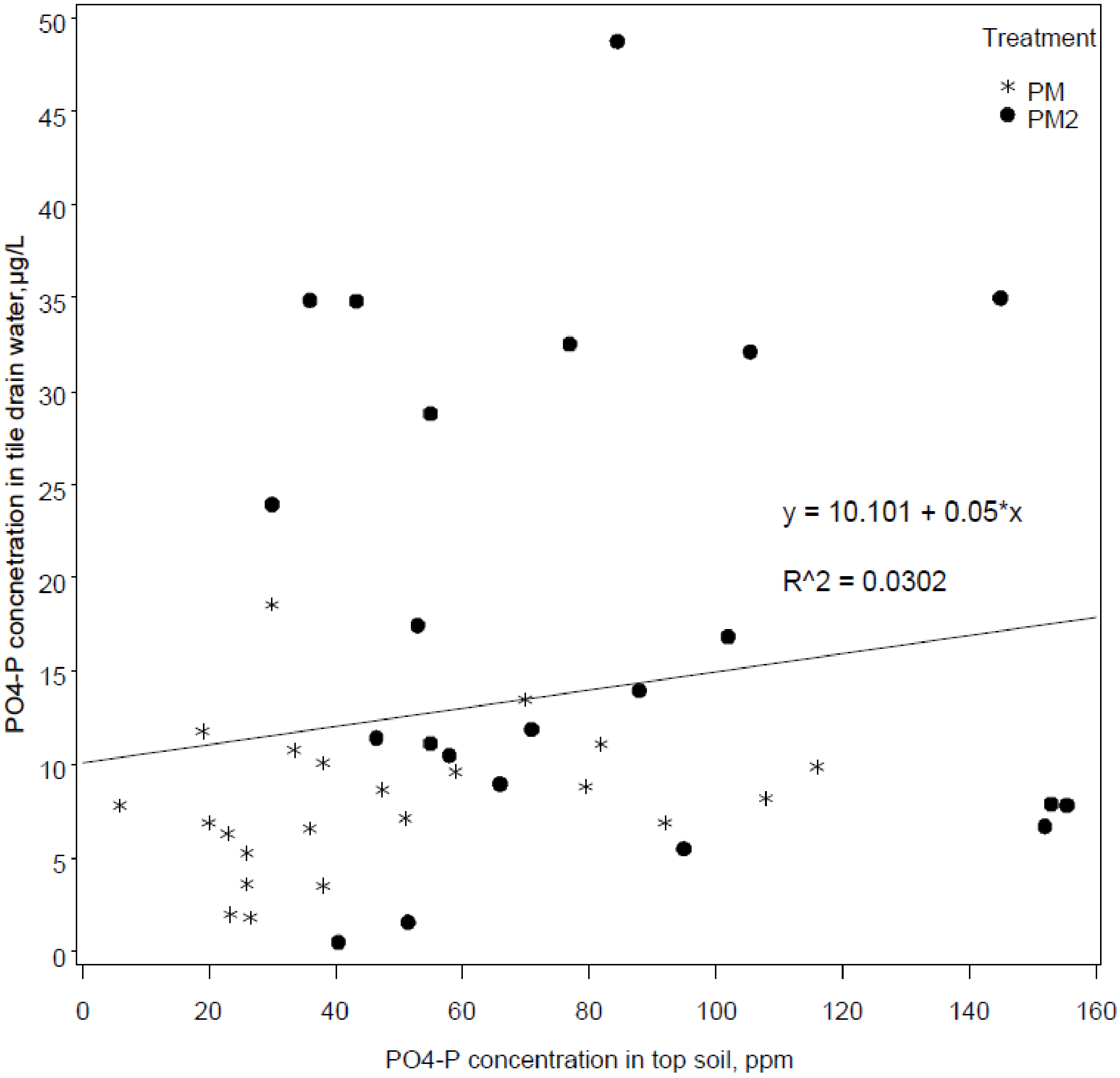

Figure 4.8 Correlation of PO_4-P concentrations in tile drain water and in top soil (0-30cm)

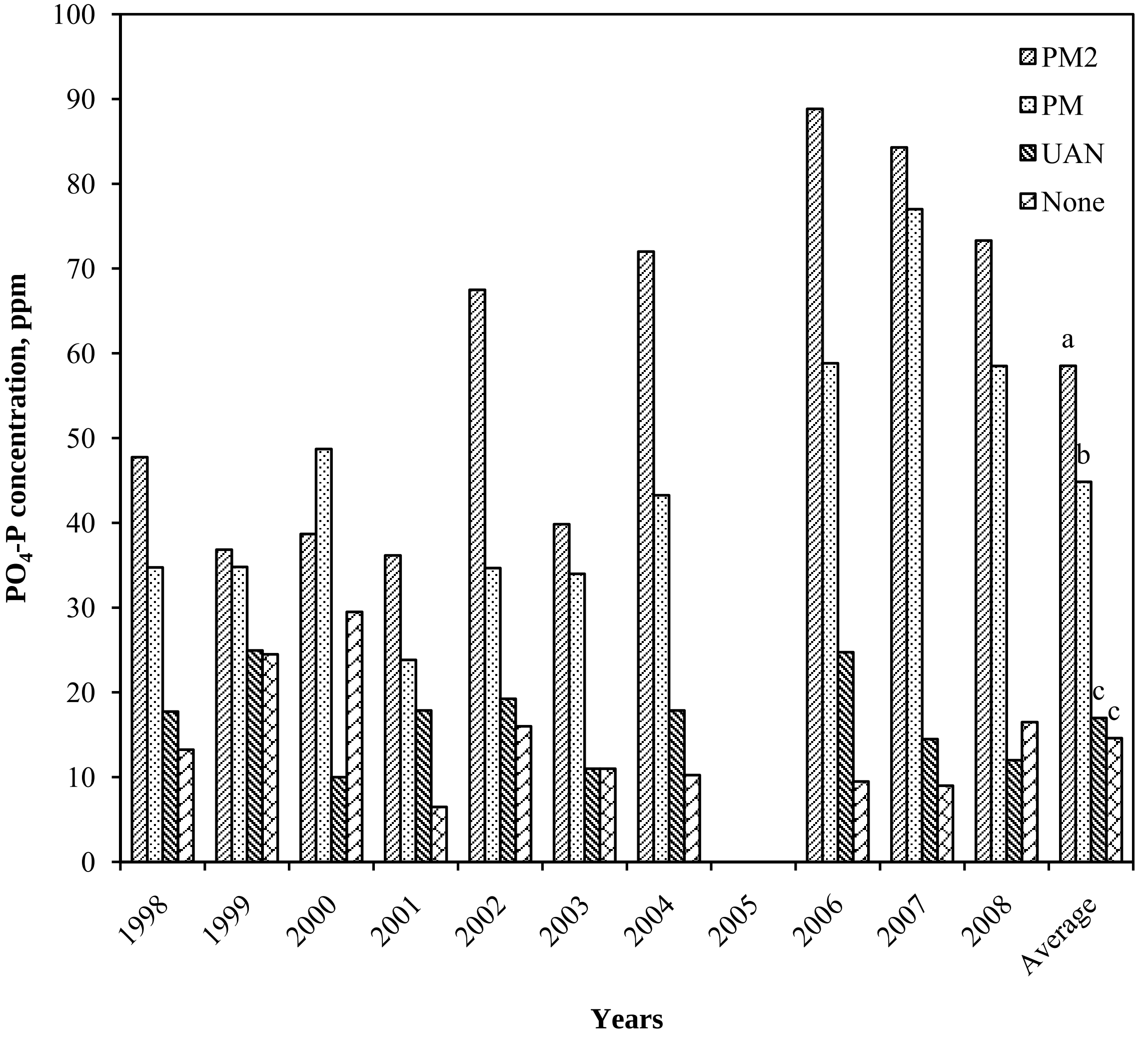

Figure 4.9 Average of PO_4-P concentrations in top soil (0-30cm) as effects of different N treatments over years

(Values followed by the same letters are not significantly different at $\alpha=0.05$)

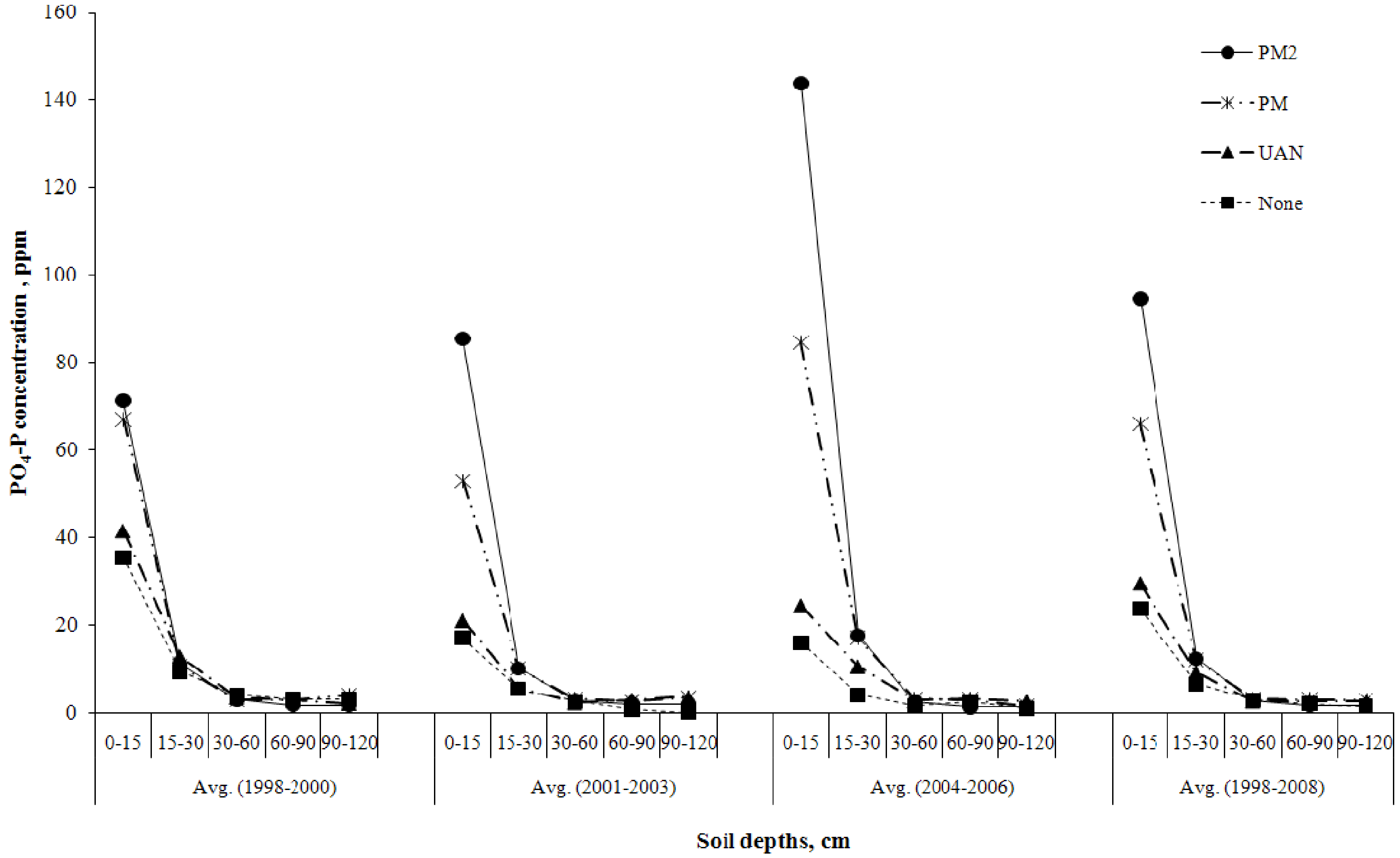

Figure 4.10 Long-term trends of PO$_4$-P concentration in soil profiles as effects of different N treatments over times

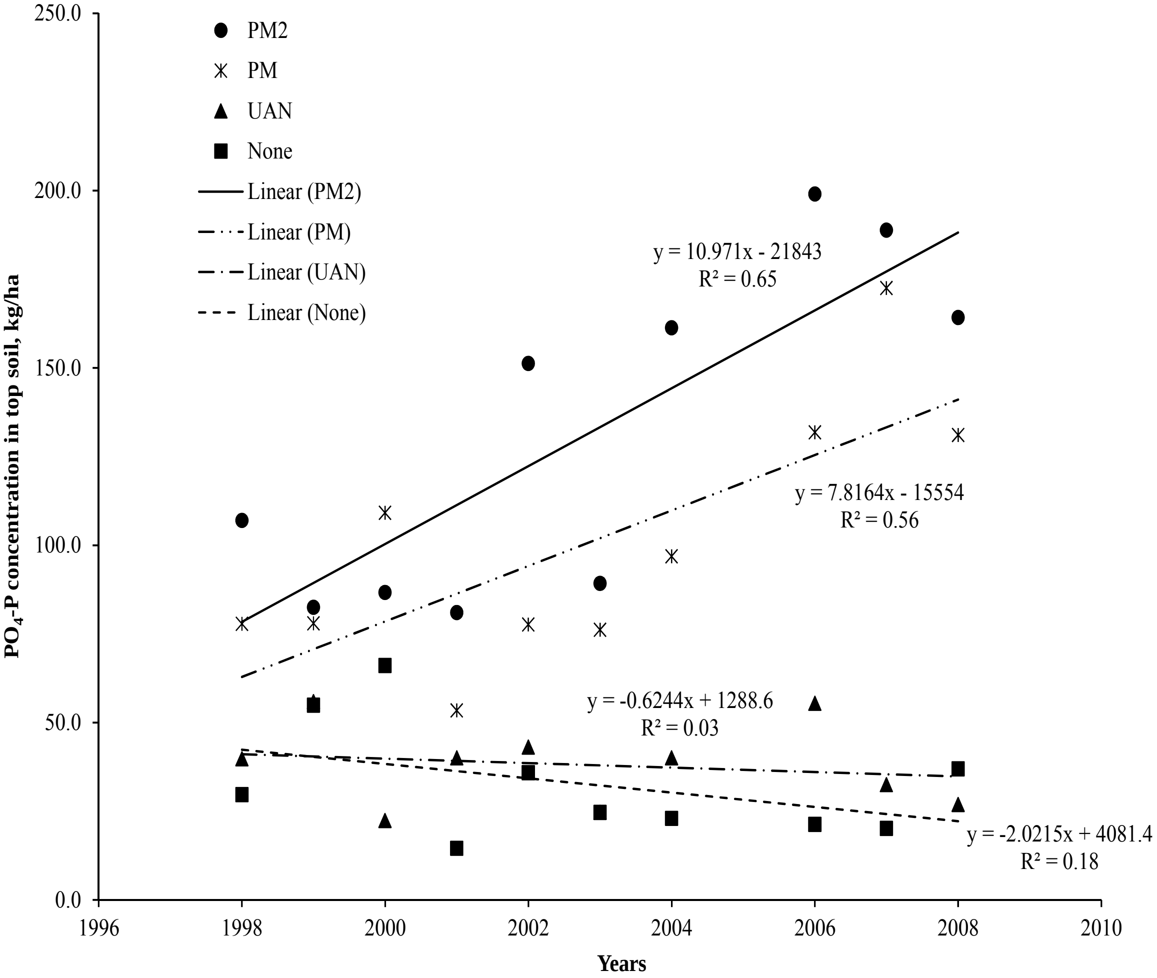

Figure 4.11 Long-term trends of PO_4-P concentrations on top soil (0-30cm) as response to different N treatments

CHAPTER 5. GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A long-term study (1998-2009) was conducted to evaluate the environmental impacts of repeated surface application of poultry manure on crop production, soil and subsurface drainage water quality under a corn-soybean rotation system in Iowa. The selected application rates of poultry manure are 168 kg-N/ha and 336 kg-N/ha. Chemical fertilizer – urea ammonium nitrate, UAN – applied at 168 kg-N/ha and a control treatment (0 kg-N/ha) is used for comparison purposes. The treatments are assigned into eleven field plots (0.1 ÷0.4 ha) - having a single central tile drainage, under an unbalance randomized complete design. Corn and soybean are planted in the same plot with corn on one half and soybean on the other half of the plot. The treatments applied on corn side only. A state of the art collection system is used to collect subsurface drainage water from tile drain. Water samples are analyzed for NO_3-N and PO_4-P. Soil cores are collected at the depth of 120cm from the surface on the corn side in Spring (before applying manure and planting) and in Fall (after harvesting corn) and divided into 5 different depths according to 5 layers of soil profile (0-15, 15-30, 30-60, 60-90, 90-120 cm). Soil samples are also analyzed for NO_3-N and PO_4-P residual concentrations.

Data from water, crop yield, corn N uptake, tile flow, NO_3-N and PO_4-P concentration in tile drain water, soil NO_3-N and PO_4-P residual concentrations are analyzed separately with year and/or month (for water quality and crop yield data), and depths (for soil data) as the repeated measures. From the overall findings of twelve year study, following conclusions may be drawn:

1. Highly variability of nutrient contents in poultry manure are observed and made a challenge to achieve the target application rate of 168 kg-N/ha and 336 kg-N/ha. A wide range of actual application rates of poultry manure is obtained and used in reference with those target rates.
2. Applying poultry manure (168 kg-N/ha) significantly increased crop yield both corn and soybean in compared with chemical fertilizer at the same rate over long-term. On average, PM2 and PM treatments give 11.5 Mt/ha and 10.4 Mt/ha respectively in compared with UAN and control (10 Mt/ha and 5.9 Mt/ha respectively).
3. Double poultry manure application rates (336 kg-N/ha, PM2 treatment) only increased less 9.8 percent of corn yield and 4 percent of soybean yield than PM treatment (168 kg-N/ha).
4. Corn stalk N uptake showed a potential to evaluate the effective N management of poultry manure and should be included in the best management practice of using poultry manure. Overall, the poultry manure treatments yield the moderate N concentration in crop residual in compared with UAN treatment.
5. Tile flow, NO_3-N concentration and losses are lowest on PM treatment in compared with PM2 and UAN treatment across years and within year. This is significantly reduced the nutrient losses overall and at the early stage of crop season (April-May) when crop does not fully development to pick up the applied nutrient yet.

6. The seasonal effects of wet-dry-normal rainfall distribution showed significant impact on NO_3-N concentration at monthly level over twelve years study. On the dry year, nitrate is stored on soil profile and leached into tile drain water and increased the NO_3-N concentration on April, May on the following years. However, PM treatment yields the lower tile flow, nitrate losses than PM2 and UAN treatments in both wet and normal years.
7. Monthly variations of PO_4-P concentration and losses in tile drain water are not much significantly differences among the treatments across the years. At yearly average, the PM2 treatment gives higher PO_4-P concentration and losses in tile drain than PM treatment and often exceeded the US-EPA standard (0.01 mg/L). In some rare events (as in years of 2008 and 2009) when high precipitation amount occurred, the PO_4-P concentration and losses from all treatments did sharply increase in tile drain water. However, the monthly and yearly average of PO_4-P concentrations from PM treatments and chemical fertilizer (UAN) are under the US-EPA standard (0.01 mg/L) during the 12 years study (1998-2009) at this research site.
8. Long-term trends of monthly distribution (April-May and Jun) of NO_3-N concentrations revealed the stabilization of the system after 8 years of study. This underscored the effectiveness and need of long-term study for the impacts of poultry manure on water quality. Short-term study may omit the trend and the effects of wide range of weather (wet, dry and normal condition).
9. The long-term effects of poultry manure on soil NO_3-N showed that PM2 treatment (336 kg-N/ha) gives significantly higher NO_3-N residual concentration

on top soil (0-30 cm) than PM and UAN treatment. On yearly average, the top soil (0-30 cm) NO_3-N residual concentrations of PM2, PM, UAN and Control are 13.4, 10.9, 10.4 and 8.3 ppm, respectively. No difference of soil NO_3-N concentrations of PM and UAN treatment at the depth 0-30 cm. On seasonal average, Spring soil test showed higher NO_3-N concentrations than those of Fall soil test across all the treatments which may be credited by the contribution of soybean from previous years through N fixation and N mineralization processes. Therefore, it may conclude that applying poultry manure at lower rate (168 kg-N/ha) appears having less NO_3-N residual concentration than that of at double rates (336 kg-N/ha) in soil profile which may be lost via run-off or leaching in tile drain water.

10. Long-term trends of PO_4-P concentration on top soil (0-30 cm) showed a positive linear increase of PO_4-P concentration under PM2 and PM treatments over years but relatively declined trends for those of UAN and control treatments. On average, PM2 treatment gives the higher soil PO_4-P concentration in top soil after harvesting than PM, UAN and control (58.5 ppm vs. 44.8, 17.0, 14.6 ppm, respectively). Thus, applying poultry manure at lower rate under this type of corn-soybean rotation may not impose the P built-up issues over long-term.
11. The correlation of NO_3-N concentration and tile flow is significant but needs further investigation because poultry manure application may change the soil physical and chemical properties over long-term application.

5.2 Recommendations for future studies

The experiment at the field 5A is continued with poultry manure applied on continuous corn instead of corn-soybean rotation as it did. Based on the findings and observations from the previous twelve years study, following recommendations are made:

1. The poultry manure's nutrient analysis and calibration process might be improved to achieve closer to the target rates (168 kg-N/ha and 336 kg-N/ha). Usually, the moisture content of the poultry manure is one of the major obstacles for calibration and surface spreading manure.
2. The collection of tile flow data may be improved with a continuous automation data logger for better calculation and measurement of tile flow volume. Also, it might help to collect more critical data on tile flow, NO_3-N concentration and losses during off growing season (October-Mar) if tile flow occurs.
3. Further investigation on horizontal flow or cross flow between field plots maybe by applying appropriate tracers (Br, N^{15}, etc.). Besides, a monthly data of fluctuation of water table of the field plot may be useful for further modeling processes and field management practice on this site.
4. A replacement of tile drainage at field plot # 6 and # 9 under UAN (168 kg-N/ha) treatment may help to add more information in comparison with PM2 and PM treatments on water quality parameters.
5. Since most of the NO_3-N concentrations from tile drainage are normally higher than 10 mg/L of the MCL standard, it may be suggested to install the bio-reactor at the out-flow of the tile drainage in each sum from the field plots to reduce the monthly and yearly average of NO_3-N below the MCL standard.

6. Water extractable soil phosphorus and other soil P fractionation should be included in the soil P test, especially at the top soil layers (0-15 and 15-30 cm) for better understanding the transformation of P species from poultry manure in soil over times.
7. The estimation of biomass from corn residual would be useful, especially with the field experiment to identify the mechanism and quantify amount of NO_3-N and PO_4-P release from corn residual under rain-fed condition and surface applied poultry manure.
8. Applying poultry manure may change physical and biological soil properties after long-term. Thus, extensive tests soil physical properties as effects of different N treatments would be useful to explain the relationships of rainfall, tile flow, NO_3-N concentration and losses and crop yield.
9. With an extensive and valuable dataset from long-term study, it might be suggested to apply some soil and water quality models (Drainmod-N, Stella, Drainage-N, etc.) and crop yield models in future studies, especially in combination of dataset from continuous corn and two different tillage experiments. The STELLA based NO_3-N models have huge potential for modeling N cycle with poultry manure applications on tile drained field and may be applied for future studies.

For the general references, it is recommended that the findings of environmental impacts of poultry manure from this study should be limited to corn-soybean production having subsurface drainage systems from a poorly drained soil and under natural rain-fed condition. For irrigation systems or well drained soils, the results might be different. Also, further studies on maximum or minimum poultry manure application rates that still give equal or higher crop yield than chemical fertilizer might be interested especially if they can be combined with different crop rotation systems and tillage systems in long-term study. Finally, it may suggest that such study on environmental impacts of poultry manure may be conducted over long time enough for the system to expose in a wide range of weather conditions before proper conclusions may be drawn.

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