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Effects of Poultry Manure Application on Phosphorus in Soil and Tile Drain Water Under a Corn-Soybean Rotation

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Abstract

Long-term application of manure can lead to phosphorus accumulation in the soil and increase the risk of P delivery to tile drainage waters. A long-term study (1998–2009) was conducted on eight tile-drained field plots, ranging in size from 0.19 to 0.47 ha, to investigate the effects of long-term surface application of poultry manure on soil phosphorus dynamics and PO4-P loss in tile drainage in Iowa under a corn-soybean rotation system. The experimental treatments included two poultry manure treatments, applied on an N basis at target rates of 168 kg N ha−1 (PM) and 336 kg N ha−1 (PM2), each with three replications, and one chemical fertilizer treatment of urea ammonium nitrate (UAN) at a rate of 168 kg N ha−1 with two replications. Actual manure application rates and estimated plant available N (PAN) varied annually. Bray1-P methods were used to analyze deep core soil samples at five depths (0–15, 15–30, 30–60, 60–90, and 90–120 cm), which were collected in the spring and fall on the half of each plot planted to corn. Tile drainage samples were collected from each actively draining plot equipped throughout the spring and fall drainage season each year, and PO4-P concentrations were analyzed. The results of this study indicated PM2 and PM resulted in a statistically significant increase in topsoil P at 0–30 cm, with no significant movement of P to deeper soil depths. Although an increase in topsoil P levels was observed with poultry manure application, average annual tile drainage P concentrations were not statistically different throughout the study with average PO4-P concentrations of 0.019 ppm with PM2 application and 0.011 and 0.012 ppm for PM and UAN, respectively. Poultry manure application at agronomical recommended application rates may be an environmentally sound fertilizer option for tile drained fine-loamy, calcareous soils under a corn-soybean rotation. However, surface runoff was not evaluated in this study, and high P levels in topsoil could contribute to elevated PO4-P runoff losses.

Keywords

Phosphorus, Water quality, Tile drainage, Poultry manure

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Environmental Indicators and Impact Assessment

Comments

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Effects of Poultry Manure Application on Phosphorus in Soil and Tile Drain Water under a Corn-Soybean Rotation

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INTRODUCTION

Iowa has been leading the nation in the production of many agricultural commodities including corn, soybeans, eggs, and ethanol for the past decade (NASS-USDA, 2010). The steady growth of these industries has posed challenges, especially regarding proper treatment and disposal of the increased volume of poultry manure (high moisture waste without bedding) and litter (lower moisture waste with bedding). In 1998, Iowa egg production, one facet of Iowa's poultry industry, generated less than 1 million Mg of poultry manure. By 2008, manure generation had more than doubled to approximately 2.3 million Mg of poultry manure (NASS-USDA, 2010; ASAE, 2005; Gollehon et al., 2001). Land application of poultry manure for corn production may be an environmentally and economically sound solution for Iowa and other egg and poultry producing regions in the U.S. (Edwards and Daniel, 1992; Shepherd, 1993; Edwards et al., 1995; Moore et al., 1995; Sharpley et al., 1998). Poultry manure can be an excellent source of three key plant nutrients (N, P, and K) and therefor serve as a source of fertilizer. However, there could be potential environmental issues associated with the utilization of poultry manure as a fertilizer if not managed properly, such as over application of poultry manure due to limited availability of nearby land for disposal (Edwards and Daniel, 1992; Daniel et al., 1994; Shepherd, 1993; Moore et al., 1995). As the costs of chemical fertilizers continue to rise, the cost of transporting to distant locations is becoming more economical, thus increasing the land available for application of poultry manure (Harmel et al., 2008).

Manure is commonly used for crop production, and generally applied on an N-basis, which may lead to over application of phosphorus. Therefore, phosphorus accumulation within the soil can result in concentrations exceeding soil P Index limits, thus increasing the risk of P delivery to surface waters and tile drainage (Sims et al., 1998; Cooperband and Good, 2002; Allen and Mallarino, 2006; Harmel et al., 2009; Smith et al., 2009). Several studies have documented the fate and transport of nutrients, such as nitrogen and phosphorus, from agricultural land via tile drainage systems, which contributes to impaired water quality in lakes, streams, and rivers (Baker and Johnson, 1981; Kanwar et al., 1988; Edwards and Daniel, 1992; Adams et al. 1994; Sharpley et al., 1998; Dinnes et al., 2002; Chinkuyu et al, 2002; and Bakhsh et al., 2010). As soil phosphorus levels increase with continued P application, a buildup of soil phosphorus near or beyond soil saturation levels may result in increasing P losses to tile drainage waters (Poirier et al, 2012; Beauchemin et al., 2003, 1998). With approximately 24.5% of Iowa's agricultural land artificially drained, transport of nutrients to tile drainage water is a concern (Qi et al., 2011; Baker et al., 2004). Therefore, key objectives of this study were to determine the effect of long-term application of poultry manure and UAN on: 1) P loss with tile drainage water; 2) the movement of phosphorus within the top 120 cm of the soil profile; and 3) accumulation of P in topsoil (0-30 cm).

MATERIALS AND METHODS

DESCRIPTION OF THE EXPERIMENTAL SITE

Field experiments were conducted from 1998 to 2009, with the first treatment application in the spring of 1998, at Iowa State University's Agronomy and Agricultural Engineering Research Farm in Boone, Iowa (Figure 1a). The long-term water quality monitoring study was conducted on eight field plots (ranging from 0.19 ha to 0.47 ha) each drained with a single subsurface tile drain, positioned 120-130 cm below the soil surface, passing through the center length of each plot (Figure 1). The site is located on soils with a Canisteo-Clarion-Nicollet association, which includes a combination of Nicollet (fine-loamy, mixed, mesic Aquic Hapludoll), Clarion (fine-loamy, mixed, mesic Typic Hapludoll), Canisteo (fine-loamy, mixed calcareous, Typic Hapludoll), and Harps (fine-loamy, mesic, Typic Calciaquoll) soils formed in glacial till under prairie vegetation with characteristic organic matter (OM) content ranging from 3-8% based on soil series (United States Department of Agriculture, 1981). Topsoil (0-30 cm) measurements for all plots in 2006 indicate lower than normal OM, ranging from 2.6 to 4.2, with a mean value of 3.4%. This soil association is characterized as having poor to very poor natural drainage which is improved by the installation of subsurface tile drainage. Select soil characteristics are detailed in Table l.

Table 1. Selected soil characteristics from Field 5A*†

Soil series	Area (%)	Slope* (%)	Drainage class*	Clay* (%)	OM*†(%)	Bulk density* (g/cm^3)
Nicollet	46	1-3	somewhat poorly	24-35	4-5	1.15-1.25
Clarion	41	2-5	well drained	18-24	3-4	1.40-1.45
Harps	10	0-2	poorly	25-35	6-7	1.35-1.40
Canisteo	3	0-2	poorly	18-35	6-8	1.20-1.30

* Slope, drainage class, clay, organic matter (OM), and bulk density values are for topsoil (0-30 cm).
† Reported OM values are the characteristic values associated with each soil series; measured OM from Field 5A indicates a lower average OM than characteristic soils.

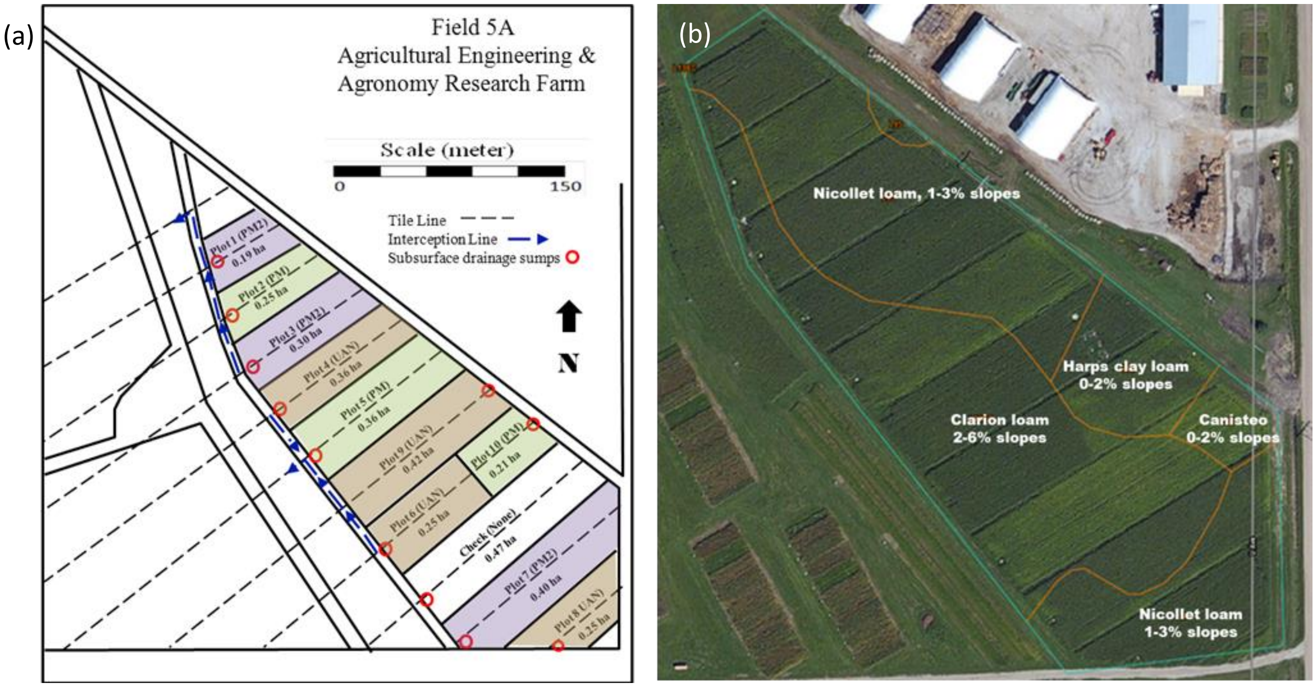

Figure 1(a). Diagram of the Field 5A research site at Iowa State University Agronomy Research Farm. Plot treatments included PM (168 kg N ha^{-1} poultry manure), PM2 (336 kg N ha^{-1} poultry manure), UAN (liquid 28% Urea Ammonium Nitrate applied at a rate of 168 kg N ha^{-1}). Two of the initial UAN treatment plots (6 and 9) were excluded from the study results due to ongoing problems with the subsurface drainage system for those plots. (Adapted from Cheatham, 2003) (b) Soil map denoting major soil types for all plots (source: http://websoilsurvey.sc.egov.usda.gov).

EXPERIMENTAL DESIGN AND TREATMENTS

Eleven established field plots with pre-existing subsurface drainage, were initially utilized for this experiment (Figure 1). Due to functional problems with the subsurface drainage systems at plots 6 and 9, all data collected from these plots were omitted from analysis in the study. Treatment continued at the plots to maintain consistency throughout the study. In addition, the Check plot, which did not receive any treatment application, was excluded from the study since only one replication had been initiated, thus reducing the study plots to eight. Corn and soybean crops were rotated within each plot annually for 12 years (1998-2009). Beginning in the spring of 1998, corn (*Dekalb 580)* and soybean (*Kruger 2426)* crops were rotated annually, with the northwest half of each plot planted to corn during even years, and the southeast half planted to corn during odd years. Soybeans were planted to the opposite half of each plot. Every fall, the half of each plot that had been planted to corn the previous year was tilled using a 20 cm depth chisel plow, leaving approximately 30% of the crop residue on the soils surface. Each spring nitrogen treatment (fertilizer or poultry manure from layer hens) of 168 kg N ha^{-1} was applied to the half of each field plot planted to corn at the recommended N rate for corn production in Iowa under a corn-soybean rotation during the entire study period of 12 years (Sawyer et al., 2002). Each of the plots planted to corn received its designated nitrogen treatment (including poultry manure) : i)168 kg N ha^{-1} (PM), ii) 336 kg N ha^{-1} (PM2), and iii) liquid 28% Urea Ammonium Nitrate (UAN) applied at a rate of 168 kg N ha^{-1}. The schematic of treatment allocation is shown in Figure 1. Both poultry manure and UAN were applied to field plots by surface broadcast and then incorporated into the soil within 24 hours by tilling to a depth of approximately 15 cm to minimize nitrogen loss via volatilization. The experimental treatments were assigned randomly to plots and maintained for the 12 years, with unbalanced replications due to the constraints of the pre-existing plot establishment. The chemical fertilizer treatment (UAN) provided only nitrogen, with no additional nutrients applied. Details of field activities can be found in the previously published work of Chinkuyu et al. (2002) and Huy et al. (2013).

POULTRY MANURE ANALYSIS

Poultry manure samples were collected before field application each year, and analyzed by Minnesota Valley Testing Laboratories Inc. in Nevada, IA for N, P and K to determine the total nutrients available and actual amount of nutrient application from poultry manure application rates (Tables 2 and 3). During the first five years of the study, multiple manure samples were collected at the time of application, and analyzed independently for nutrient characteristics, including; moisture content, percent N as total Kjehldahl nitrogen (TKN), and percent P as P_2O_5-P, and percent K as K_2O. In subsequent years, a single composite sample was collected from the manure storage pile for analysis before application. Manure was applied on an N basis, often resulting in high P application rates.

Table 2. Poultry Manure Analysis with Total Nutrients available (1998-2009). Manure was analyzed at application for each plot in 1998-2000, with standard deviation shown in parentheses. A composite sample was collected and analyzed for the all plots for subsequent years (2001-2009).

	Manure Analysis				Total Nutrients (lbs/Ton)		
Year	**% as H_2O**	**% as TKN**	**% as P_2O_5**	**% as K_2O**	**N**	**P**	**K**
1998	47.50 (3.40)	1.50 (0.17)	0.97 (0.14)	1.34 (0.28)	29.95 (3.36)	8.45 (1.26)	22.23 (4.65)
1999	49.82 (5.28)	3.01 (0.08)	4.29 (0.39)	2.08 (0.31)	60.20 (1.67)	37.41 (3.43)	34.47 (5.20)
2000	32.42 (1.38)	3.21 (0.66)	3.85 (0.32)	2.33 (0.20)	64.23 (13.11)	33.57 (2.83)	38.68 (3.25)
2001	56.97	2.16	2.72	2.01	43.27	23.69	33.37
2002	53.70	1.41	2.24	1.20	28.20	19.53	19.92
2003	74.60	1.85	1.37	1.06	37.07	11.95	17.65
2004	69.90	2.40	2.10	1.13	48.00	18.31	18.76
2005	25.03	2.10	6.14	3.14	42.00	53.54	52.07
2006	58.43	2.01	2.55	1.18	40.20	22.24	19.59
2007	76.33	1.77	0.99	1.38	35.40	8.63	22.91
2008	59.13	2.15	2.04	1.13	43.00	17.79	18.76
2009	58.43	2.72	1.88	1.74	54.47	16.39	28.88
Average (StDev)	55.19 (15.37)	2.19 (0.56)	2.59 (1.51)	1.64 (0.64)	43.83 (11.22)	22.63 (13.13)	27.27 (10.58)

While PM and PM2 manure application rates averaged of 177 kg N ha^{-1} and 353 kg N ha^{-1}, respectively, less N was readily available for crop growth (Table 3). Plant available N (PAN) from the poultry manure was initially determined by assuming 75% N applied was available during the first year of application, with no additional N available in subsequent years. More recent estimation methods suggest up to 60% N available during the first year of poultry manure application, with up to 10% of the previous year's N applied available in the second year of crop growth (Iowa State University Extension, 2008). Since the manure application was rotated between the two halves of each plot during even and odd years, no carryover of previously applied N was assumed for this study. A 5% loss of PAN was assumed at time of application for all years. Therefore, PAN from poultry manure was likely over estimated throughout the study using the early estimation methods. Allowances for available nitrogen from the previous year's soybean crop were not factored. Table 3 details the rates of manure application, along with the PAN estimation of N in applied manure using both the previous and current estimation methods. The average long-term manure application rate was close to the target application rates, while the PAN was considerably lower than the target rates. The UAN was assumed to be readily available for crop growth, with 100% PAN assumed at time of application.

Table 3. Poultry Manure Application Rates Achieved (1998-2009), at Target Application Rates of 168kg N ha^{-1} and 336 kg N ha^{-1} with Estimated Plant Available Nitrogen (PAN) from 1998-2009.

	PM (168 kg N ha^{-1})			**PM (336kg N ha^{-1})**		
	Rate of Application*	Estimated N available (PAN)		Rate of Application*	Estimated N available (PAN)	
		current methods[a]	early methods[b]		current methods[a]	early methods[b]
Year	**-------------------------- kg N ha^{-1}------------------------------**					
1998	159 (39)	91	113	350 (96)	200	249
1999	300 (75)	171	214	444 (52)	253	316
2000	87 (13)	50	62	329 (29)	188	235
2001	194 (4)	111	138	330 (40)	188	235
2002	113 (6)	65	81	203 (7)	116	145
2003	213 (21)	122	152	344 (41)	196	245
2004	248 (7)	141	177	491 (12)	280	350
2005	186 (16)	106	133	350 (13)	200	249
2006	184 (11)	105	131	340 (12)	194	242
2007	170 (11)	97	121	345 (13)	197	246
2008	183 (13)	104	130	343 (25)	195	244
2009	179 (5)	102	128	361 (6)	206	257
Average (StDev)	177 (61)	105 (31)	132 (39)	353 (68)	201 (39)	251 (49)

* N application as Total Kjeldahl Nitrogen. A 5% loss of PAN was assumed at time of application. [a]Current PAN estimation methods used in this study assume 60% N available from the current year's manure application. [b] The early method used for estimation of PAN during this study assumed 75% PAN from the first year's manure application, with no additional N availability in subsequent years.

Soil Core Sample Collection and Phosphorus Analysis

Soil sample analysis was conducted at Iowa State University Agronomy Department's Soil and Plant Analysis Laboratory. Soil samples were collected from all plots in the spring and/or fall of most years. Three deep core soil samples (0-120cm) were collected from the half of each plot planted to corn during the fall and spring of 1998-2004 and 2006-2007. In 2008, deep core samples were only collected in the spring. The resulting holes from deep core sample collection were filled with bentonite clay. Composite samples from each plot were analyzed at five depths (0-15, 15-30, 30-60, 60-90, and 90-120cm) for phosphorus using Bray P methods.

Tile Drainage Water Sample Collection and Analysis

Flow weighted tile drainage water samples were collected from the plots weekly, twice weekly during periods of high tile flow, and/or immediately after moderate to heavy rainfall events in most years. During periods of extremely low tile flow or no flow, drainage water sampling was less frequent. Subsurface drainage water monitoring equipment was not installed at the check plot until 2000. The tiles of two UAN plots (6 and 9) did not flow throughout the study period; therefore, drainage samples could not be collected for those plots. Subsurface flow volume was measured and recorded using a HOBO Pendant Event Data Logger connected to a Trion water meter register. The logger recorded a time stamp with each switch closure every time one cubic foot of water passed through the Neptune T-10 water meter. A 20-liter plastic jar was positioned in each of the drainage sumps to collect a representative composite drain water sample as a portion of the total tile drainage water by using an orifice tube installed in the drainage outlet pipe (Nguyen et al, 2013). Drainage water samples collected from the monitored plots were analyzed for PO_4-P on a Lachat autoanalyzer at Iowa State University's Agriculture and Biosystems Engineering Water Quality Research Laboratory (WQRL) using an ammonium molybdate method, with a detection limit of 0.001mg PO_4 L^{-1} as P .

Statistical Analysis

Statistical analysis was conducted for the soil test phosphorus (STP) Bray 1-P data using the Mixed procedure, with analysis of linear trends with treatment and year, and comparison of LSMEANS (SAS, 2009). Microsoft Excel 2013 was also used to illustrate trends in soil P levels in the top 30 cm as a function of time. An R^2–value (Coefficient of determination) was calculated and used to evaluate the model that best fit the data. Where applicable, the control plot (None) data were used for comparison only, and not included in statistical analysis of the data. Drainage PO_4-P concentrations were log transformed to ensure normal distribution. The GLIMMIX procedure was performed to evaluate the observed differences in PO_4-P annual flow-weighted concentrations to tile drainage with time during the 12-year study. In all of the statistical analyses, a priori $\alpha = 0.05$ probability levels were used.

Results and Discussions

Poultry Manure Characteristics and Application Rates Over Time

Poultry manure nutrient content and other characteristics can be highly variable (Harmel et al., 2009). The high variability in the nutrient content of poultry manure over time (Table 2) reveals the difficulties that existed in trying to achieve the target application rate of 168 kg N ha^{-1} or 336 kg N ha^{-1}. Poultry manure characteristics differed throughout the twelve-year study period, with moisture content ranging from 25.0% to 76.3%. This variability in moisture content may have contributed to the high variability in N and P content in the poultry manure over the years and resulted in fluctuating manure application rates, which has been observed by other researchers as well (Harmel et al., 2011). The 12-year average manure moisture content was 55.1%, with a standard deviation of 15.2%. This high moisture variability in poultry manure may have contributed to differences observed in poultry manure nutrient contents when analyzed as a single composite sample before field application, or analyzed as either multiple samples collected near to or at the time of field application. Some variations in nutrient content measurements were apparent between sampling methods, with an average N content of 2.46%±0.94% when multiple samples were analyzed compared to 2.08±0.35% when a single composite sample was analyzed. The relatively high standard deviation in manure characteristics between multiple samples collected and analyzed during the years 1998 through 2002 suggest manure N application rates could be under or over estimated by as much as 29% when relying on a single composite sample analysis. The P content was also somewhat higher when multiple samples were analyzed compared to a single composite sample, with the average P_2O_5 as 2.73%±1.31% when multiple samples were analyzed compared to 2.26%±1.64% when a single composite sample was analyzed.

EFFECTS OF POULTRY MANURE ON SOIL TEST PHOSPHORUS (STP) IN THE SOIL PROFILE

Deep core soil samples at five depths (0-15, 15-30, 30-60, 60-90, and 90-120cm) were collected from the treated half of each plot for analysis of soil test phosphorus (STP) levels using Bray1-P methods. Figure 2 shows that most of the PO4-P was accumulated in the top two depths (0-15 cm and 15-30 cm) with virtually no movement of P to the deeper subsoil layers. Research indicates that the phosphorus sorption capacity is specific to local conditions and soil characteristics; therefore, it is difficult to assign a general environmental threshold value for STP concentrations (Dou et al., 2009; Fang et al., 2002; Sims et al., 2002). Guidance for interpretation of Bray 1-P tests indicates 16-20 ppm P in topsoil as optimum for corn and soybean growth on Iowa soils, with suggested corresponding phosphorus fertilizer application rates of 62 Kg ha-1.

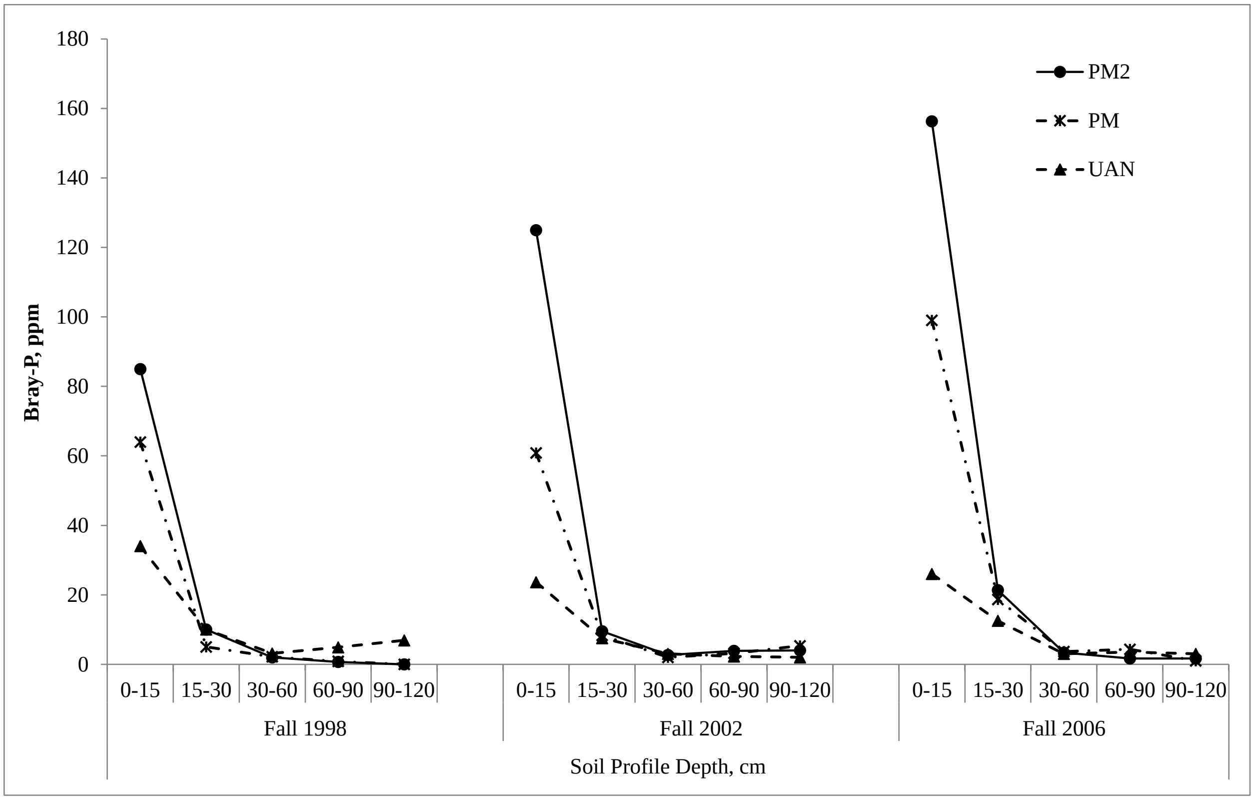

Figure 2. A comparison of fall STP with depth over time. Due to the immobile nature of phosphorus in soil, it is unlikely the large difference in Bray-P measurement at this depth was accurate.

Phosphorus characteristics of agricultural soils treated with various P sources for 10 or more years were evaluated by Dou et al.(2009), with a finding that different soils treated with poultry manure at P application rates ranging from 90-150 kg ha^{-1} had variable P saturation of 57- 89% . These values corresponded to concentrations of 336-691 ppm Melich3-phosphorus (M3-P). Sims et al. (2002) suggested an agri-environmental interpretation of STP (M3-P) of below 50 ppm as below optimum, 51-100 ppm as optimum, greater than 100 ppm as above optimum, and greater than 150 ppm as an environmental concern requiring a reduction of P, while Fang et al. (2002) suggests a much lower threshold of 65-85 ppm STP (M3-P) to limit surface runoff P from Minnesota River basin soils. By 2006, the soils in this study receiving the PM2 treatment, which corresponds with an average P application of 371 ppm, had reached 156 ppm using Bray-P methods. Although Iowa does not have an environmental threshold based solely on STP, at Bray-P levels of 21 ppm and above, zero application of phosphorus is agronomically recommended for corn crops.

Mehlich 3 and Bray P have reasonably comparable results in most soil types, with M3-P methods generally resulting in higher analyzed values in calcareous soils (Gartley et al., 2002). A limited comparison of M3-P and Bray-P analysis for the current study (results not shown) indicates that the soil samples for this study with high STP using Bray-P methods also tested higher using M3-P methods. Based on the low concentrations of P measured in the tile drainage water, a 150 ppm threshold does not appear to be valid for the Clarion-Nicollet-Webster soil association of this study. Manure application, especially poultry manure, and various soil, hydrologic characteristics, and site specific landscape management practices, have resulted in increased phosphorus sorption capacities far exceeding literature specified threshold P levels. Mozzaffari and Sims (1994) found considerable P sorption potential in well-drained soils receiving ongoing poultry manure applications, with estimated P sorption maximums well exceeding 2000 ppm. Additional analysis, including P-saturation evaluation, may be useful to predict the additional P-sorption capacity.

EFFECTS OF POULTRY MANURE TREATMENTS ON PO_4-P CONCENTRATIONS IN TILE DRAINAGE WATER

Several studies have investigated the relationship between manure application and P concentrations in surface runoff (Daniel et al., 1994; Shreve et al., 1995; Sauer et al., 2000; Wood et al., 1999). However, little research has been done to evaluate the impact of long-term poultry manure application on P loss with subsurface drainage water. Preferential flow to subsurface tile drains may result in an increase in nutrient and chemical losses to water bodies, including P losses to surface drainage waters (Shipitalo et al., 2004, Addiscott et al., 2000). However, this increased P loss was limited to the first few rainfall events immediately following fertilizer or manure application (Owens and Shipitalo, 2006). The results of the study indicated higher, although not statistically significant, PO_4-P losses to subsurface drainage water when poultry manure was applied at twice the agronomically recommended rate (PM2) compared to both the UAN and PM treatments.

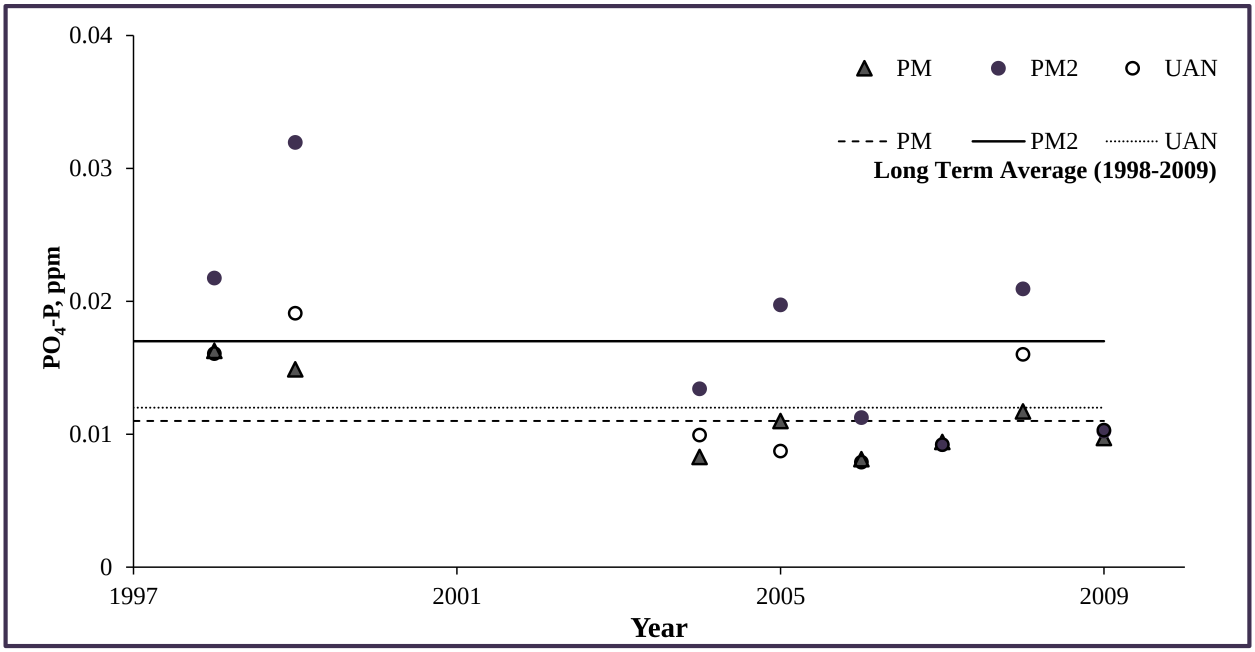

Figure 3. Average Annual Tile Drainage PO4-P Concentrations from 1998-2009. The solid line represents the average PO_4-P concentration of 0.019 ppm from plots treated with PM2 from 1998-2009, with the dashed lines representing the average PO_4-P concentrations of 0.011 ppm for PM and None, and 0.012 for UAN plots during the same time span. Tile drainage PO_4-P data was not available from 2000-2003. The check plot (None) did not have monitoring equipment in 1998 and 1999.

The tile drainage PO_4-P concentrations with all treatments were highly variable throughout each year's drainage season. The average annual PO_4-P concentrations in tile drainage water ranged from 0.009 to 0.038 ppm for PM2 treatment. The highest PO_4-P concentrations (two samples of 0.127 ppm and one sample of 0.173) were measured from a total of three samples collected from the PM2 drainage plots within two weeks of the crops being planted in early to late May in 1998 and 1999. This highest value measured coincides with an exceptionally high PM2 application rate and manure PO_4-P content in 1999 (Table 3), and the second highest annual rainfall amounts recorded during the study period (data not shown).This combination of increased PO_4-P applications from poultry manure, increased rainfall amounts, and stage of crop growth likely had a strong impact PO_4-P transport to subsurface drainage water.

Although the average PO_4-P concentrations in tile drainage water remained below the EPA's recommended threshold of 0.076 ppm, as total P for streams in the corn belt and northern great plains ecoregion (U.S. EPA, 2000), tile drainage samples from the PM2 plots exceeded this threshold value for PO_4-P in three samples.

EFFECTS OF POULTRY MANURE TREATMENTS ON TOPSOIL P AND LONG-TERM TRENDS IN STP WITH ANNUAL APPLICATION

Spring soil analyses for 1998 and 1999 indicate the initial background STP levels, with similar initial phosphorus conditions measured for PM2, PM, and UAN, with error bars indicating the variance between plots receiving the same treatments (Figure 4). The initial average topsoil (0-30 cm) STP for the PM plots was the highest of all treatments, with 19.9 ± 3.3ppm in 1998, and 26.5 ± 4.4ppm in 1999. The UAN had the largest initial variation, with 18.6 ± 11.5ppm and 24.8± 15.3ppm in 1998 and 1999, respectively. An increased accumulation of soil P was observed with both PM2 and PM treatments over time, while an overall decrease in P was observed with UAN from 1998-2008.

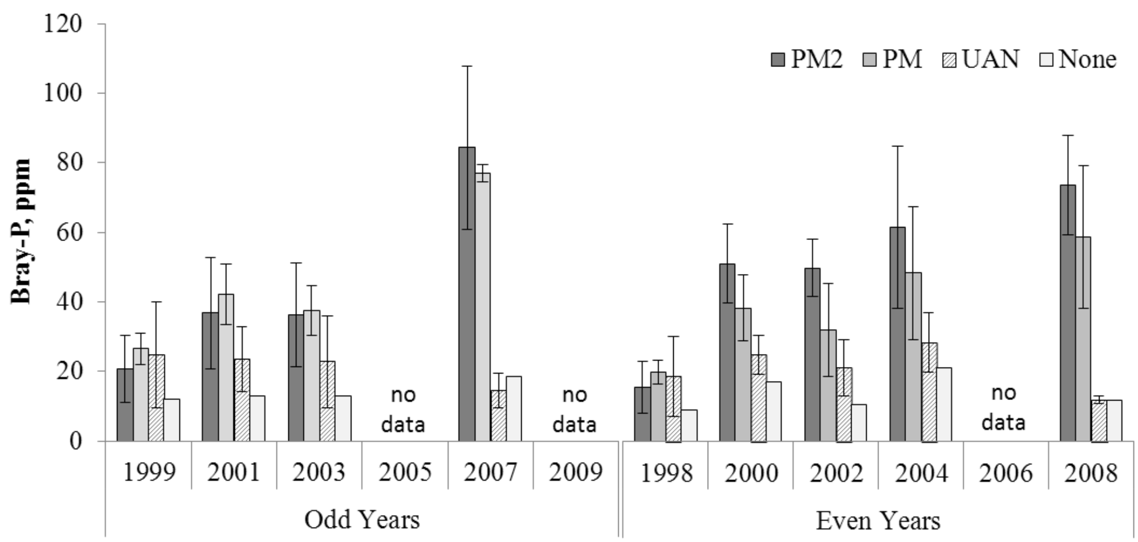

Figure 4. Average annual spring Bray-P analysis for topsoil (0-30cm). STP for 0-15 cm and 15-30 cm soil depths were averaged to represent the 0-30 cm Bray-P for years 1998-2004. In 2007 and 2008, composite soil samples were analyzed for 0-30 cm. Treatments were applied on alternating halves of each plot annually when planted to corn, with soil samples collected from the half of each plot receiving treatment.

Field collected data on soil P concentrations clearly demonstrated high variability in soil characteristics between and within plots, resulting in unexpected differences in topsoil P levels between years. Because soil P is relatively immobile, large changes in soil P would not be expected without the physical addition of phosphorus, such as adding high P poultry manure. More intensive soil sampling, including an increased number of samples per plot, may have reduced year to year variability in soil P levels for some plots.

A comparison of the long-term trends in P concentrations (Bray-P extraction method) in the topsoil for spring and fall seasons, and overall average for the year is presented in Figure 5. Although the PM plots had higher initial STP levels, the PM2 STP levels were approximately 15 ppm higher than the PM plots by spring 2008. The differences in STP concentrations for the poultry manure treatments were more pronounced with the fall analysis (Figure 5b), likely due to the spring manure application. The annual data on STP for the topsoil was available for both spring and fall season during even years from 1998-2004, and 2007.

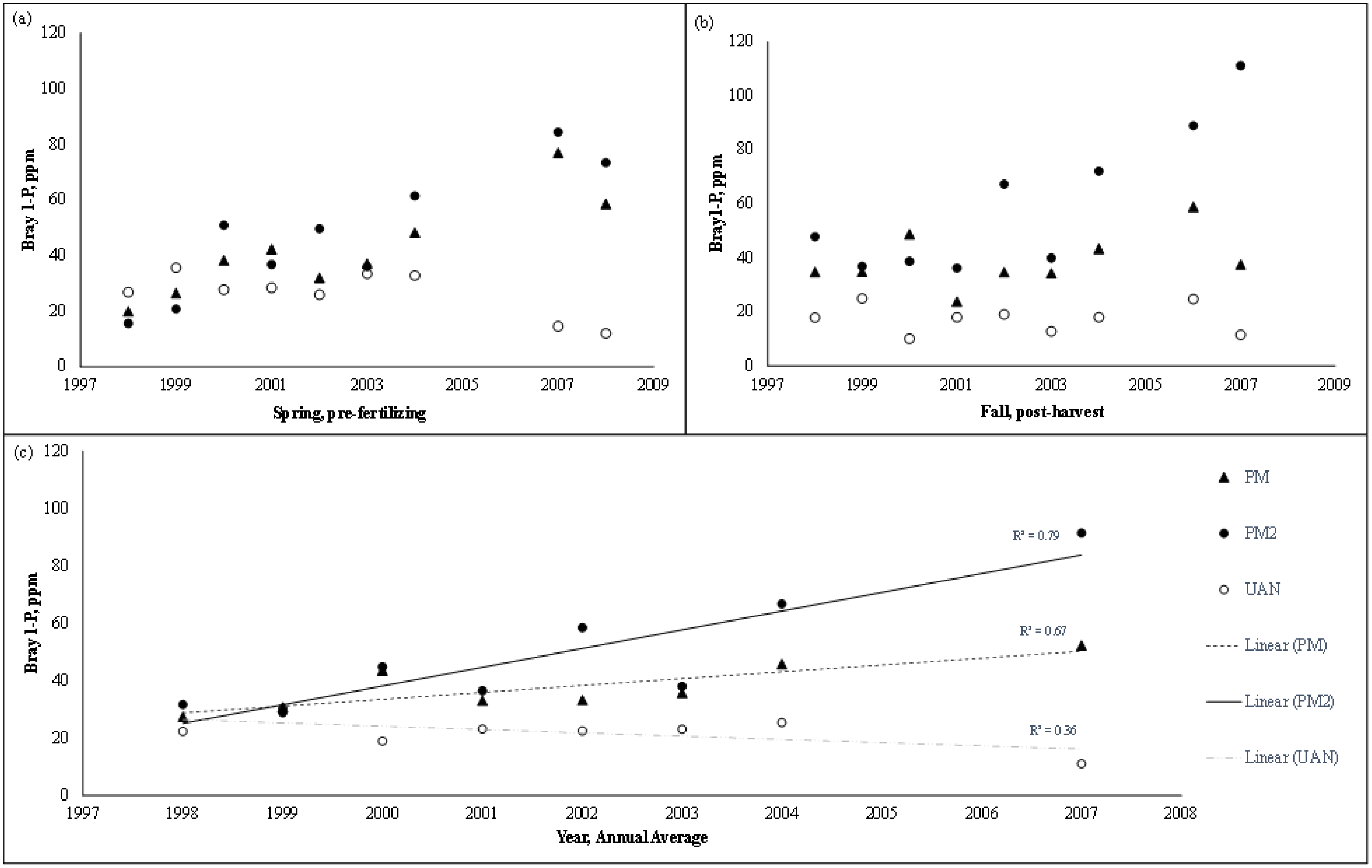

Figure 5. Long-term trends in topsoil (0-30cm) Bray1-P Extractable P. (a) spring soil core sample results, before manure application; (b) fall, post-harvest soil core results; (c) averaged spring and fall results for available years.

Linear regression is illustrated in Figure 5c, with R^2values included. PM2 and PM clearly have increasing trends based on the R^2values. A weaker (downward) relationship seems apparent with UAN over time. Due to the repeated measures of this study, it was necessary to perform additional statistical analysis (Mixed procedure in SAS) to determine trends. PM and PM2 had statistically significant increasing trends, while UAN did not show a significant trend over time. Other similar studies have also shown an accumulation of P in the topsoil when manure is applied at rates above crop uptake requirements (Daigh et al., 2009). Daigh et al. (2009) concluded that accumulation of topsoil P with annual manure application may pose prolonged environmental consequences since increased topsoil P concentrations persist for years after manure application has been discontinued. Therefore, it is reasonable to predict that as the soil P concentrations continue to follow an increasing trend with poultry manure application, there will be more instances of exceeding the recommended threshold in drainage. In addition, PO_4-P is not the only likely form of P exported with tile drainage waters. Total P includes both organic and inorganic (PO_4-P) phosphorus.

SUMMARY AND CONCLUSIONS

The long-term impacts of poultry manure application rates on soil P accumulation, P loss with tile drainage water, and crop yield, under a conventional corn-soybean rotation in Iowa, were determined in this 12-year study. The results of this study indicated that there were no apparent changes in soil test phosphorus (STP) at soil depths below 30 cm during the 12-year study period. Therefore, it was concluded that there was no significant movement of P from long-term poultry manure applications to deeper within the soil profile during a period of twelve years. The highest accumulations of phosphorus, based on STP, were observed in the top 0-15 cm and 15-30 cm soil layers, with the highest concentrations observed in the top 0-15 cm. A long-term trend in continuous buildup of phosphorus or P accumulation was observed in the topsoil (0-30 cm) over the 12-year period of this study when poultry manure was applied at both the single (PM) and double (PM2) the agronomical recommended rates for N application for a corn-soybean rotation in Iowa. Phosphorus application rates in this study averaged 201 kg ha^{-1} and 371 kg ha^{-1} for PM and PM2 treatments, respectively. This trend of P accumulation in the top 30 cm of soil profile was observed in the spring as well as in the fall growing season.

The long-term impacts of poultry manure application on PO_4-P concentrations in the tile drainage water were visible, but the average P concentrations remained well below the EPA recommended criteria 0.076 ppm concentration for streams in Iowa, with an average P concentrations of 0.019 ppm with PM2 application, and 0.011 ppm for PM and UAN. In this study, no clear trends were observed in PO_4-P concentration in tile drainage water as a function of experimental treatments or time. Therefore, it can be concluded that poultry manure applications to crop fields did not increase the risk of transport of phosphorus to subsurface tile drain water during the 12 years of this study. Since site specific soil characteristics, hydrologic conditions, and land management practices strongly influence the soils' phosphorus sorption capacity; it is likely that this finding is specific to the fine-loamy calcareous soils in the upper Midwest, which have high phosphorus sorption capacity (von Wandruszka 2006; Mozaffari and Sims, 1996). Continued long-term data collection on P transport would be useful to evaluate the P saturation levels of soils at the present site of this study, supported by laboratory analysis of the soils P sorption capacity.

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