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PHOSPHORUS LOSSES THOUGH SUBSURFACE DRAINAGE IN A LOAMY SOIL OF IOWA: EFFECTS OF RATES, TIMING AND METHOD OF SWINE MANURE AND FERTILIZER APPLICATION

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ABSTRACT Phosphorus is one of the most important and essential mineral nutrients for corn and soybean production. Phosphorus is primarily transported to surface water bodies with surface runoff from agricultural fields as it is strongly absorbed to the soil particles. However, small amounts of dissolved phosphorus lost with subsurface drainage water can be immediately available for accelerating eutrophication in surface water bodies at critical phosphorus concentrations of 10 to 20 μgL^{-1}. A long-term subsurface drainage water quality study was conducted at the Nashua research site located in the Northeast part of Iowa, USA. The overall goal of this study was to investigate the effects of the application of swine manure and commercial fertilizer (ammonium nitrate, UAN) on phosphorus leaching to subsurface drainage water under a corn-soybean rotation. Effects of different application timings and rates were also evaluated in this long-term study (2001-2006). The results of this study indicated that phosphorus concentrations in subsurface drain water, from all experimental treatments, were highly variable and not consistent with the amount of phosphorus applied from swine manure and/or fertilizer. Manure applications at higher rates however, resulted in significantly higher phosphorus concentrations (p=0.05) in subsurface drain water in comparison to other treatments in the soybean year. Spring manure applications generally showed lower phosphorous concentration in subsurface drain water in comparison with fall manure applications, although differences were not statistically significant (p=0.05).

Keywords: Liquid swine manure, phosphorous, spring and fall, subsurface drain flow, UAN fertilizer.

INTRODUCTION Phosphorous (P) and nitrogen (N) are essential plant nutrients. The demand and consumption of both elements have been increasing for the last several decades to grow more food to feed the growing population in the world. The increased use of P and N in agricultural watersheds also has resulted in excessive leaching and runoff losses of P and N to rivers, lakes, groundwater and oceans. Excessive accumulation of P and N in surface water bodies can be a major water quality concern for natural ecosystems. *Eutrophication* can be promoted at the P concentration of 10 to 20 μgL^{-1} (Daniel et al.,1998; Heathwaite and Dils, 2000; USEPA, 1994). Howarth et al. (1995) estimated that there was about 33 million tons of P discharged to water bodies in the world each year, with half of that amount being carried by rivers.

Dissolved P and particulate P are two common forms of P found in subsurface drainage water, of which particulate P form is found at higher fractions (Haygarth et al., 1998; Heathwaite and Dils, 2000). Transport of P through subsurface drainage water was normally considered negligible because of its strong adsorption characteristic to soil particles, which can be transported with eroded soil to surface water runoff (Hansen et al., 2002; Heathwaite and Dils, 2000; Sims et al., 1998). However, several studies have shown that P could be delivered to subsurface drainage water in high concentrations because of preferential flow (Beauchemin et al., 1998; Delgado et al., 2006; Djodjic et al., 2004; Heathwaite and Dils, 2000; Sims et al., 1998; Smith and Withers, 2001; Stamm et al., 1998). There is a strong relationship between dissolved P concentration in subsurface drainage water and soluble P available in the top soil (Hesketh and Brookes, 2000; Ulén, 1999). Results from field experiments conducted by Heathwaite and Dils (2000) showed that the concentration of total P was found at very high levels with concentrations of 1000 μgL^{-1} in subsurface drain flow, which is excessively higher than the recommended critical value to prevent *eutrophication*. Algoazany et al. (2007) reported that the annual average soluble P mass loads in subsurface drainage water were higher than that in the runoff water because much higher volume of rainfall (16.1%) was removed through subsurface drain water in comparison to the volume of surface runoff (2.6%). Gilliam et al. (1999) reported that the majority of P was transported though subsurface drain water in sandy loam soil in humid regions. The most favourable conditions that resulted in higher delivery of P to subsurface drainage water are high P availability (P level is higher than that crop needs) in the soil, manure application to soils with the presence of preferential flow, especially when rainfall occurred after long period of dry soil conditions. Soil type and tillage systems also appear to contribute to the movement of P in subsurface drainage waters (Algoazany et al., 2007).

Manure application to the field land can provide sufficient nutrient sources for growing crop. However, with manure applications to agricultural fields on long-term basis results in higher nitrate - nitrogen concentrations in subsurface drainage water and higher soil test P levels in the top soil (Bakhsh et al., 2005; Kinley et al., 2007). Different types of manure and commercial fertilizers, their application rates, timing and method, cropping systems, and tillage practices are the main factors that affect the transport of soluble P to subsurface drainage water (Algoazany et al., 2007; Bakhsh et al., 2005; Bakhsh et al., 2002). Higher concentration soluble P was found in subsurface drainage water in fields receiving poultry and swine manure (Kinley et al., 2007). The overall objective of this study was to evaluate the effects of six different nutrient management systems on subsurface water quality. The specific objectives of the research were: (1) to determine the impact of recommended swine manure application rates, based on phosphorus needs of crops, on P losses to subsurface drainage water; (2) to study the long-term effects of over-application of swine manure on phosphorus P losses with subsurface drainage and (3) to study the long-term effects of spring and fall injection of swine manure and commercial fertilizer application method on phosphorus losses with subsurface drainage water.

MATERIAL AND METHODS

Research site description Field experiments were conducted at the Iowa State University's Northeast Research Center near Nashua, Iowa. The study site has 36, 0.4 ha plots (58.5 by 67 m). The main dominant soils at this site are Floyd loam (fine-loamy, mixed, mesic Aquic Hapludolls), Kenyon loam (fine-loamy, mixed, mesic Typic Hapludolls), and Readlyn loam (fine-loamy, mixed, mesic Aquic Hapludolls) (Kanwar et al., 1997). These soils lay over a highly fluctuating water table conditions, from about 20 cm to 160 cm. Subsurface drains were installed at the site in 1979 at 1.2 m depth to maintain lower water tables and attain high crop productivity. Tile drain water from the central tile line of each plot was collected and measured using a flow meter installed in each independent sump at the end of the plot. Subsurface drainage water samples were collected every week when tiles were flowing. More details on this subsurface drainage system and water sampling and monitoring systems installed at this site can be found in Kanwar et al. (1999).

Experimental and treatment design All 36 plots at this field research site were used for this particular study for a total of six systems under corn-soybean rotation. Each system had two treatments. The first five systems were under chisel tillage practice whereas system 6 was under no-till practice. Each treatment was replicated three times for corn and soybean cropping year in a randomized complete block design. Liquid swine manure was applied to system 2, 4 and 6, whereas UAN was used in systems 1, 5 and partly in system 3. Both liquid swine manure and commercial fertilizer (ammonium nitrate, UAN) were applied at the N based rate of 170 kg-N ha^{-1} to the corn crop. No swine manure was applied to the soybean crop in all systems, except for soybean treatment in system 4 (SS4), where swine manure was applied at a rate of 225 kg-N ha^{-1}. Liquid swine manure used in this study was taken from a finishing swine facility. More details on experimental treatments are given in Table 1.

Table 1: Experiment treatments at the research site on liquid swine manure and commercial fertilizer application rates, methods, and timings study.

System	Crop	Treatment Symbol	Application timings, method and sources	Application rate (kg)	
				N-based rate	P-based rate
1	Corn	CS1	Spring-preplant UAN injected	170	
	Soybean	SS1	-		
2	Corn	CS2	Fall-swine manure injected	170	
	Soybean	SS2	-		
3	Corn	CS3	Fall manure* + Sidedress spoke UAN injected	170	* P based rate of 67
	Soybean	SS3	-		
4	Corn	CS4	Fall-swine manure injected	170	
	Soybean	SS4	Fall-swine manure injected	225	
5	Corn	CS5	Spring-Sidedress inject UAN with LCD	170	
	Soybean	SS5	-		
6	Corn	CS6	Spring-swine manure injected	170	
	Soybean	SS6	-		

Analysis and calculation of orthophosphate concentration and losses The subsurface drain flow water samples were collected in the field and preserved with concentrated sulphuric acid 2%, and then stored at $4^{o}C$ until analysis. The water samples were analyzed in the Water Quality Laboratory of the Department of Agricultural Biosystems Engineering at Iowa State University in Ames, Iowa. Orthophosphate (PO_4-P) concentrations in water were determined using the automated flow injection ascorbic acid method with a Lachat Quickchem 8000 Automated Ion Analyzer system (APHA 1985). The PO_4-P mass loss with subsurface drainage water for each interval of sampling was calculated by multiplying the PO_4-P concentrations ($\mu g\ L^{-1}$) with subsurface drain water effluent volume and reported in grams per hectare ($g\ ha^{-1}$). The annual flow weighted average PO_4-P concentrations for each year were calculated based on the cumulative PO_4-P loss and sum up of drainage effluent for the entire monitoring season for that year according to a similar way of calculating flow weighted average nitrate- nitrogen concentrations as reported by Bjorneberg et al. (1998), Karlen et al. (2004), and Bakhsh et al. (2005).

Statistical Analysis Statistical analysis was performed to test the effects of block, yearly conditions, and application rates of liquid swine manure and commercial fertilizer on subsurface drainage volume as well as PO_4-P concentration and mass load to subsurface drainage water. The general linear method procedure (GLM) using SAS version 9.1 for Windows (SAS Institute, 2003) was used to analyze the data. Analysis of variance (ANOVA) tables were developed for dependent variables. Treatment means within each year and over the years were tested at alpha level of 0.05 for all statistical tests, using the least significant difference (LSD) method.

RESULTS AND DISCUSSIONS Results of the analysis of variance for subsurface drainage volume, flow weighted concentration, and mass loss of PO_4-P in subsurface drainage water across 6 years average for the comparison among treatments in three systems 1, 3 and 5, and treatments in the other three systems 2, 4, and 6, are presented in Tables 3 and 5, respectively.

Table 2: Precipitation data from 2001-2006 at the Nashua research site (mm)

Year	Month									Growing Season[a]	Drainage Season[a]	Annual Total
	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.			
2001	41	63	148	64	70	73	149	40	26	504	674	714
2002	14	109	75	75	179	155	51	54	7	535	719	719
2003	30	97	99	155	76	13	48	15	69	391	602	603
2004	109	46	284	74	155	74	56	51	36	643	884	898
2005	13	58	109	201	99	152	168	8	30	729	838	838
2006	42	122	34	116	59	68	126	38	48	402	652	697
Average	42	82	125	114	106	89	100	34	36	534	728	745
Normal[b]	51	87	104	132	117	116	85	62	54	554	808	881

[a] Growing season was May through September, and drainage season was March through November.
[b] Source: National Climate Data Center for Charles city, Iowa, 1971-2000.

Precipitation and subsurface drainage flow A summary of monthly precipitation during the drainage seasons from year 2001 to 2006 are presented in Table 2. The long-term average precipitation (1970-2000) at the research site was 881 mm yr^{-1}. This long-term average precipitation data was taken from weather station in Charles City, Iowa, about 16.5 km from the research site. Six year average (2001-2006) annual precipitation at the research site was 745 mm yr^{-1}, or 15% below the long-term normal for the study site. The years 2004 and 2005 were considered as wet years in comparison to other years. The lowest rainfall was observed in 2003, 32% below the normal value at the site. Six-year average precipitation during the drainage seasons for this site was 728 mm yr^{-1}, which was 10% below the long-term average precipitation in drainage season. Again for two years, 2004 and 2005, drainage season precipitations were higher than the normal by 9% and 4%, respectively. Subsurface drainage flow varied from year to year. It fluctuated mainly according on precipitation patters. Results of this 6-year study showed that all treatments in systems 2, 4 and 6 generally discharged higher volumes of subsurface drainage volume (Tables 3 and 5).

Effects of different fertilizer application methods and swine manure application rates based on crop needs of P on phosphorus leaching The summary results of effects and comparison of treatment means of six different treatments in systems 1, 3 and 5 are presented in Table 3, and 4 and Figure 1.

Table 3: Analysis of variance for PO_4-P leaching loss and concentration in subsurface drainage water when averaged across the years (2001-2006) for all treatments in systems of 1, 3, and 5

Source of Variability	df	Subsurface drainage flow (p-value)	PO_4-P loss in subsurface water (p-value)	Flow weighted average PO_4-P concentration
Block	3	<0.01	0.57	0.62
Treatments (trt)	5	0.45	0.45	0.56
Error a	10			
Year	5	<0.01	0.01	0.01
Trt*Year	25	<0.01	0.1	0.57
Residual	60			

Table 3 shows the effect of different independent variables of block, treatments and years to subsurface drainage flows, PO_4-P leaching loss and concentrations in the subsurface drainage. It shows that the block and yearly weather has highly significant effects on tile flow volumes ($p<0.01$) when averaged across six years of data. This indicates the effects of spatial variability of soil types and landscape attributes at the study site. Similar results were described by Bakhsh and Kanwar (2005). No significantly different effects of block and treatments were found on PO_4-P leaching losses and PO_4-P concentrations in subsurface drainage water. However, yearly weather significantly influenced subsurface drainage flow volume and PO_4-P leaching loss as well as concentration in that flow when averaged across six years (2001-2006). These results showed that timings as well as application methods and sources have no significantly effects on phosphorous leaching when the same N application rate was applied from manure or commercial fertilizer.

Table 4 shows that almost all yearly values of PO_4-P concentrations were below the critical value to preserve water quality from *eutrophication*. However, three treatments (CS1, CS3 and SS3) resulted in higher PO_4-P concentrations in 2002 when low subsurface drainage flow was observed. Although there was no significant difference between treatment means of PO_4-P concentrations, CS3 treatment, the one received fall manure application at the P-based rate of 67 kg ha^{-1}, did generate the highest concentration (23 μg L^{-1}) when averaged across 6 years of data. This PO_4-P concentration of 23 μg L^{-1} was high enough to promote *eutrophication* in water.

Table 4. Treatment means for annual subsurface drainage and flow-weighted average PO_4-P concentration (μg L^{-1}) in drainage water for systems 1, 3, and 5.

Year[a]	Treatments											
	Annual subsurface flow (mm)						Phosphorus concentration (μg L^{-1})					
	CS1		**CS3**		**CS5**		**CS1**		**CS3**		**CS5**	
2001	73.2	b	94.1	b	97.4	b	2.2	a	2.5	a	1.9	a
2002	3.0	b	0.8	b	29.9	a	72.9	a	114.7	a	8.6	a
2003	50.4	b	68.1	b	59.5	b	2.7	a	2.2	a	10	a
2004	87.5	ab	47.6	b	75.2	ab	4.8	a	7.2	a	7.1	a
2005	45.8	a	78.4	a	89.1	a	6.1	a	5.1	a	4.2	a
2006	54.2	b	60.1	ab	94	a	5.1	a	6.4	a	4.9	a
Average	**52.3**	**a**	**58.2**	**a**	**74.2**	**a**	**15.6**	**a**	**23.0**	**a**	**6.12**	**a**
	SS1		**SS3**		**SS5**		**SS1**		**SS3**		**SS5**	
2001	91.3	b	91.4	b	164.3	a	3.4	a	2.4	a	2.9	A
2002	10.2	ab	5.5	ab	16.4	ab	9.3	a	11.9	a	9.6	A
2003	65.9	b	40.3	b	103	a	5.7	a	1.6	a	8.3	A
2004	85.6	ab	140.1	a	61.4	ab	3.0	a	4.7	a	3.2	A
2005	50.7	a	58.4	a	51.3	a	5.0	a	3.6	a	5.1	a
2006	50.3	b	72.5	ab	63.8	ab	4.6	a	4.7	a	5.0	a
Average	**59.0**	**a**	**68.2**	**a**	**76.7**	**a**	**5.2**	**a**	**4.0**	**a**	**5.7**	**a**

[a] Means within years and on average followed by the same letter are not significantly different at p=0.05

Figure 1 shows the average PO_4-P loss in subsurface drainage water in systems 1, 3 and 5. Two out of six years showed significant differences in PO_4-P mass loss and they were related to volume or drainage water discharge.

Effects of timings and application rates of liquid swine manure on phosphorus leaching Table 5 shows the effects of different independent variables of block, treatments, and years on subsurface drainage flow, PO_4-P leaching loss and concentration in subsurface drainage water for all treatments in systems 2, 4 and 6.

Table 5 shows that the block and yearly weather again had highly significant effect on tile flow volumes ($p<0.01$) when averaged across six years of data. These results are similar to those that have been described between all treatments in previous systems 1, 3 and 5. Treatments also had significant effect on subsurface drainage water volume ($p=0.05$). No significantly different effects of block and treatments were found on PO_4-P leaching loss and concentration in subsurface drainage water. Yearly weather had significantly influenced the subsurface drainage flow volume but had no significant effect on PO_4-P leaching loss and concentration when averaged across six years (2001-2006).

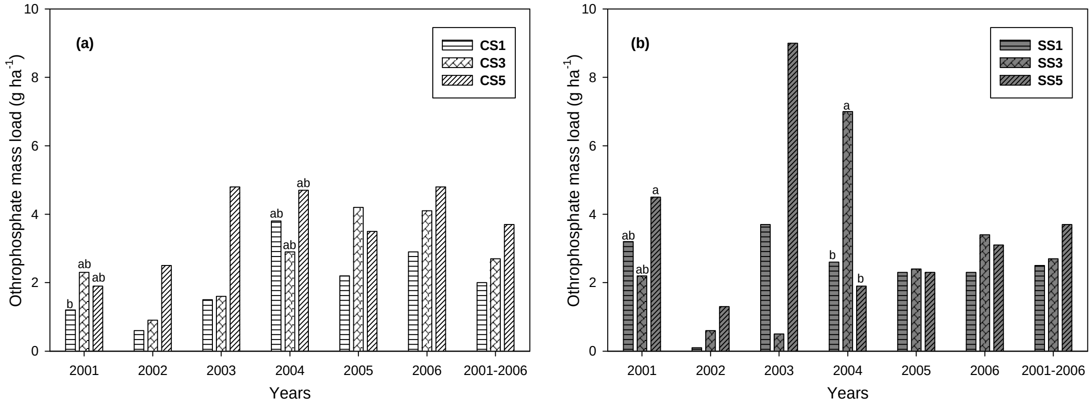

Figure 1. Yearly and overall six-year average phosphorus mass load with subsurface drain flow, for (a) corn crop and (b) soybean crop treatments in systems 1, 3 and 5. (Values without letter or same letter at the top of bars are not significantly different)

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Table 5: Analysis of variance for subsurface drainage flow, PO_4-P leaching losses and concentration averaged across the years (2001-2006) in systems of 2, 4, and 6.

Source of Variability	df	Subsurface drainage flow (p-value)	PO_4-P loss with subsurface water (p-value)	Flow weighted average PO_4-P concentration
Block	3	<0.01	0.94	0.81
Treatments (trt)	5	<0.01	0.57	0.58
Error a	10			
Year	5	<0.01	0.2	0.3
Trt*Year	25	<0.1	0.7	0.75
Residual	60			

Table 6 shows the yearly PO_4-P concentrations and 6-year average values for all treatments in systems 2, 4, 6. Treatment SS4, for which liquid swine manure was applied to the soybean crop, did result in the highest average PO_4-P concentration (13µg L^{-1}) not significant different. Swine manure applied in the fall (CS2) also had the tendency of generating higher PO_4-P concentrations in comparison to fall application (CS6). All soybean treatments in systems 2, 4 and 6 that had swine manure applied to corn treatment also resulted in higher PO_4-P concentrations in subsurface drainage water when compared to   treatment in systems 1, 3 and 5 (Tables 4 and 6).

Figure 2a shows PO_4-P losses with subsurface drain flow for three systems that used liquid swine manure as a nutrient source. Only two years (2002 and 2006) showed significantly different PO_4-P losses with subsurface drainage water with highest loss resulted from CS2 treatment and the lowest loss resulted from treatment SS4. Other years did not show significant difference in PO_4-P leaching losses among all treatments. However, PO_4-P losses were observed to be changing from year to year as the results of weather conditions.

Table 6: Treatment means for annual subsurface drainage flow and flow weighted average PO_4-P concentration (µg L^{-1}) in drainage flow for systems 2, 4, and 6.

Year[a]	Treatments											
	Annual subsurface flow (mm)						Phosphorus concentration (µg L^{-1})					
	CS2		**CS4**		**CS6**		**CS2**		**CS4**		**CS6**	
2001	75.6	cbd	84.3	bc	169.9	abc	12.2	a	3.7	ab	3.1	ab
2002	46.1	ab	11.6	bc	49	a	12.9	a	7.9	a	11.5	a
2003	55.4	b	61.1	bc	124.7	abc	14.2	a	6.5	a	7.0	a
2004	142.6	ab	91.3	b	79.4	b	14.2	a	5.4	a	7.1	a
2005	53.8	b	73.1	ab	117.8	abc	13.7	a	9.2	ab	4.8	b
2006	107.4	a	58.9	a	98.7	a	11.3	a	4.9	a	5.9	a
Average	80.1	cbd	79.4	cd	106.6	bc	13.1	a	6.2	a	6.6	a
	SS2		**SS4**		**SS6**		**SS2**		**SS4**		**SS6**	
2001	190.1	ab	132.5	abc	205.6	a	1.3	b	9.8	ab	4	ab
2002	10.8	bc	7.6	c	63.6	a	15.2	a	13.3	a	11.4	a
2003	140.1	ab	90.7	ab	145.6	a	9.1	a	40.6	a	6.8	a
2004	98.6	b	118.6	ab	171.8	a	4.5	a	8.8	a	7.7	a
2005	150.2	ab	70.9	ab	131.6	ab	4.7	b	3.5	b	6.1	ab
2006	54.7	a	56.1	a	112.9	a	7.8	a	6.3	a	5.9	a
Average	107.7	b	79.4	cd	138.5	a	7.1	a	13.7	a	6.2	a

[a] Means within years and on average followed by the same letter are not significantly different at p=0.05

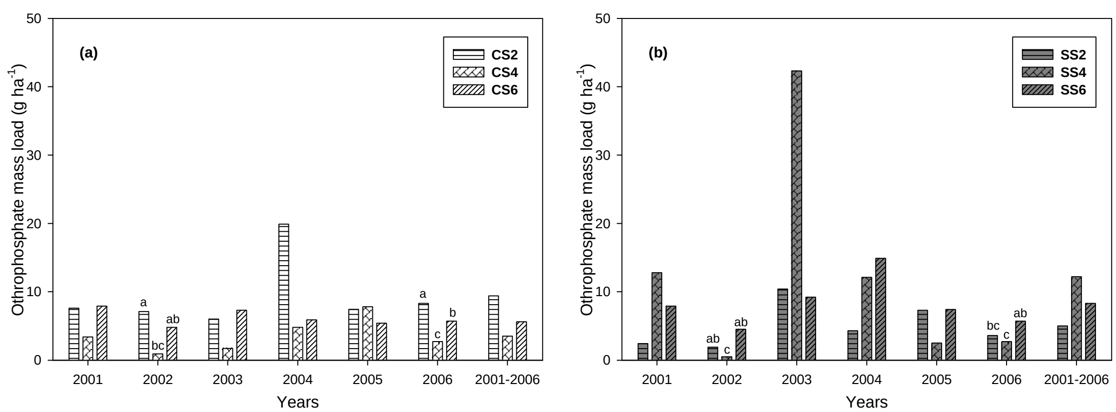

Figure 2. Yearly and overall six-year average PO_4-P losses with subsurface drain water , (a) for the treatments on corn crop and (b) for the treatments on soybean crop in the systems 2, 4, 6. (Values without letter or same letter at the top of bars are not significant different)

CONCLUSION The results of this study indicated that phosphorus concentrations in subsurface drainage water from all experimental treatments investigated in this study, were highly variable and not always consistent with the amount of phosphorus applied from swine manure and/or commercial fertilizer. All treatments did not show significant effects on PO_4-P concentrations and PO_4-P losses with subsurface drainage water. Swine manure application rates, based on crop needs of phosphorus, resulted in higher PO_4-P concentrations in subsurface drainage water. Over-manure application to the soybean crops, however, also resulted in a higher PO_4-P concentration ($p=0.05$) in subsurface drain water among all treatments in the soybean year. Spring manure applications generally showed lower PO_4-P concentration in subsurface drain water in comparison with fall manure applications, although differences were not statistically significant ($p=0.05$).

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