8-1-2007

Nutrient Concentrations of Runoff During the Year Following Manure Application

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Abstract. *Little information is currently available concerning temporal changes in nutrient transport following the addition of manure to cropland areas. This study was conducted to measure nutrient transport in runoff as affected by tillage and time following the application of beef cattle or swine manure to a site on which corn (*Zea mays *L.) was grown. Rainfall simulation tests were initiated 4, 32, 62, 123, and 354 days following land application. Three 30 min simulated rainfall events, separated by 24 h intervals, were conducted at an intensity of approximately 70 mm h^{-1}. Dissolved phosphorus (DP), particulate phosphorus (PP), total phosphorus (TP), NO_3-N, NH_4-N, total nitrogen (TN), electrical conductivity (EC), and pH were measured from 0.75 m wide by 2 m long plots. Concentrations of DP, TP, and NH_4-N, in general, declined throughout the year on both the no-till cattle and no-till swine manure treatments. Tillage did not significantly affect concentrations of DP, PP, TP, NH_4-N, or pH on the swine manure treatments, but significant variations in these variables were measured over time. Under no-till and tilled conditions on both the cattle and swine manure treatments, the smallest concentrations of DP, NO_3-N, NH_4-N, and TN occurred on the final test date. The increase in pH of runoff during the study is attributed to the addition of $CaCO_3$ to the rations of beef cattle and swine. Tillage appeared to have less of an impact on runoff nutrient transport from cropland areas than length of time since manure application.*

Keywords. *Eutrophication, Land application, Manure management, Manure runoff, Nitrogen movement, Nutrient losses, Phosphorus, Runoff, Tillage, Water quality.*

Beef cattle and swine manure can be effectively used as a valuable nutrient source for crop production. However, nutrients transported in runoff from land application areas can cause off-site environmental impacts (Sharpley et al., 1994). The use and management of phosphorus (P) is important because of its dominant role in the eutrophication of aquatic ecosystems (Sims and Kleinman, 2005). Factors influencing P loss from agricultural watersheds include site management (application method and timing), source management (applied P and soil P), and transport factors (channel effects, connectivity to a stream, erosion, irrigation runoff, proximity of P-sensitive water, sensitivity of P input, soil texture, subsurface flow, and surface runoff) (Sharpley et al., 2003). When rainfall occurs soon after manure application, soil nutrient values may not significantly impact runoff nutrient concentrations (Eghball et al., 2002a). Mineralization and immobilization of organic P are two of the physical processes that influence the concentration of P in the soil solution. The quantity of P in solution at a given time is generally <1% of the total quantity of P in the soil (Pierzynski, 1991). The effective depth of interaction between overland flow and soil P was reported by Sharpley (1985) to range from 1 to 37 mm, depending on rainfall intensity and slope gradient.

Nitrate in runoff from land application areas may be carried to rivers and lakes, creating a hypoxic zone (<2 mg L^{-1}) for marine life in the Gulf of Mexico (Turner et al., 1997). Aquatic organisms may also be adversely affected if NH_4-N concentrations in surface waters are >2.5 mg L^{-1} (USEPA, 1986). Important processes that influence nitrogen (N) conversions following land application include denitrification, leaching, mineralization, nitrification, and volatilization (Reynolds, 2006). Microorganisms play a major role in N transformations from manure (Smith and Peterson, 1982). The biological, chemical, and physical processes affecting manure N dynamics can vary significantly over time.

Substantial research has been performed examining the effects of manure application rate and method on P and N transport in runoff. Much less information is available concerning temporal changes in runoff nutrient concentrations following land application. The objective of this study was to determine whether tillage and time following the application of beef cattle and swine manure to a commercial corn (*Zea mays* L.) crop affected runoff nutrient transport.

Submitted for review in June 2006 as manuscript number SW 6502; approved for publication by the Soil & Water Division of ASABE in August 2007.

This article is a contribution from the USDA-ARS in cooperation with the Agricultural Research Division, University of Nebraska, Lincoln, and is published as Journal Series No. 15244.

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Materials and Methods

Study Site Characteristics

Field tests were conducted from June 2002 to May 2003 at the University of Nebraska Roger's Memorial Farm located 18 km east of Lincoln, Nebraska, in Lancaster County.

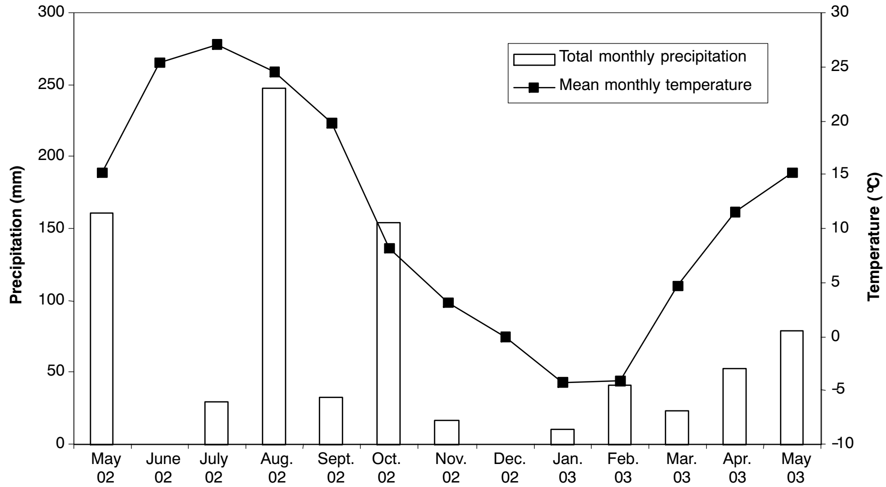

Figure 1. Total monthly precipitation and mean monthly temperature at the study site from May 2002 to May 2003.

The Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) at the site contained 11% sand, 54% silt, and 35% clay, and 18.5 g kg^{-1} of organic C in the top 15 cm of the soil profile. The soil developed in loess under prairie vegetation and had a mean slope of 7%. The site had been cropped using a grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), winter wheat (*Triticum aestivum* L. cv. Pastiche) rotation, under a no-till management system, and was planted to soybean during the 2001 cropping season. Total monthly precipitation and mean monthly temperature at the study site are presented in figure 1. From June 2002 to May 2003, 686 mm of precipitation was received at the experimental location. Mean annual precipitation in the area is 711 mm.

Field rainfall simulation tests were initiated 4 (3 June 02), 32 (1 July 02), 62 (31 July 02), 123 (30 Sept. 02), and 354 (19 May 03) days following manure application. Twelve plots, each 0.75 m wide × 2 m long, were established along the contour for use during each of the five test intervals. Thus, tests were conducted on 60 separate plots during this study. The 12 plots examined during a selected test period were not used during subsequent investigations. The plots were not protected from natural rainfall between test intervals, and runoff resulting from natural precipitation events was not monitored.

A block containing six no-till plots and a block with six tilled plots were randomly selected for each of the five test intervals to facilitate the use of a 5 m wide disk-tillage implement. Within each no-till and tillage block, beef cattle manure was applied to three plots and swine manure was applied to the other three plots in a randomized design. As part of the disking operation, soil may be transported from its original location. Therefore, manure was applied prior to disking on the tillage plots to an area larger than the final plot dimensions to provide more uniform manure incorporation over the experimental plot area.

Plot Preparation

Beef cattle and swine manure were collected at the University of Nebraska Agricultural Research and Development Center near Ithaca, Nebraska. A feedlot operation was the source of the beef cattle manure. The liquid swine manure was obtained from a pit located below a slatted floor. The production unit had been in operation for two months and contained 100 swine weighing 36 to 45 kg that were fed a corn-soybean diet.

Beef cattle and swine manure were applied on 30 May 2002 at rates of 56.1 and 37.1 Mg ha^{-1}, respectively, using an estimated N rate required to achieve a target corn yield of 9.4 Mg ha^{-1}. Application rates were determined assuming 40% N availability during the first year following application for beef cattle manure (Eghball and Power, 1999) and 70% N availability for swine manure (Gilbertson et al., 1979). Manure characteristics and application rates of N and P are given in table 1.

The 30 tillage plots were disked up and down the slope on 31 May 2002, and the entire 60-plot area was then planted along the contour to corn using a 76 cm row spacing with a target population of 69,000 plants ha^{-1}. Herbicide was applied as needed during both 2002 and 2003 to prevent weed growth. The study area was harvested using a combine on 17 Sept. 2002 (107 days following manure application).

Supplemental information on soil nutrient values (table 2) was collected to help explain expected differences among nutrient runoff measurements. Before the rainfall simulation events were initiated for each test interval, six soil cores were collected by hand from each plot in 0-5 and 5-15 cm depth increments using a 1.9 cm diameter soil probe. The 18 soil

Table 1. Manure characteristics and application rates of nitrogen and phosphorus.

Manure Type	NO_3-N[a] (g kg^{-1})	NH_4-N (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Water Content (g kg^{-1})	EC[b] (dS m^{-1})	pH	Total N (kg ha^{-1})	Total P (kg ha^{-1})
Cattle	0.04	0.27	6.73	3.61	266	12	8.1	377	203
Swine	0.0001	4.07	5.82	1.01	956	25	6.8	216	37

[a] Nutrient concentrations of the beef cattle and swine manure were determined on a dry and wet basis, respectively.
[b] EC = electrical conductivity; EC and pH for beef cattle manure were determined in 1:5 manure:water ratio; EC and pH for swine manure were measured without dilution.

Table 2. Soil characteristics as affected by manure type, tillage condition, and time since manure application.

Depth	Manure	Tillage	Time (days)	Date	WSP[a] (mg kg^{-1})	BKP[b] (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	EC[c] (dS m^{-1})	pH
0-5 cm	None	No-till	4	3 June 02	6.3	80	7	2.9	0.5	6.9
	Cattle	No-till	32	1 July 02	18.3	223	30.9	12.1	1.1	6.8
			62	31 July 02	9.2	148	42.2	3.2	1	6.8
			123	30 Sept. 02	9.8	126	25.7	2.4	0.7	6.6
			354	19 May 03	11.9	130	7.2	2.1	0.5	7.1
		Tilled	32	1 July 02	7.6	96.1	23.9	6.4	0.8	6.6
			62	31 July 02	16.4	202	43.4	15.5	1.1	6.9
			123	30 Sept. 02	12.4	165	44.8	4	0.9	6.6
			354	19 May 03	16.1	167	9.8	2.9	0.5	7
	Swine	No-till	32	1 July 02	8.2	118	57.3	25.2	1	6.8
			62	31 July 02	6.3	119	69.1	15.2	1.2	6.7
			123	30 Sept. 02	6.1	85.8	21.1	2.9	0.6	6.6
			354	19 May 03	8.7	89.6	7.2	2.5	0.4	7.2
		Tilled	32	1 July 02	3.5	71.3	37.2	4.8	0.8	6.5
			62	31 July 02	6.8	107	47.7	11	1	6.8
			123	30 Sept. 02	5.9	90.7	39.5	2.3	0.8	6.7
			354	19 May 03	11.2	103	7.6	2.5	0.4	7.1
5-15 cm	None	No-till	4	3 June 02	1.1	18.3	5.1	2.6	0.3	5.6
	Cattle	No-till	32	1 July 02	1.4	23.1	7.7	4.7	0.4	5.5
			62	31 July 02	0.9	16.2	9.3	3.1	0.4	5.5
			123	30 Sept. 02	1.1	26.7	14.3	2.2	0.4	5.3
			354	19 May 03	0.6	7.5	5.9	1.9	0.3	5.3
		Tilled	32	1 July 02	1.4	25.9	9.5	5.2	0.4	5.6
			62	31 July 02	0.9	16.8	9.7	5.2	0.4	5.7
			123	30 Sept. 02	1.5	40.3	22.4	2.6	0.5	5.3
			354	19 May 03	2.5	38.3	9	2.5	0.3	5.6
	Swine	No-till	32	1 July 02	1.3	16.5	13.1	6.1	0.4	5.4
			62	31 July 02	0.7	13.6	9.6	3.9	0.4	5.2
			123	30 Sept. 02	0.8	12.6	13.8	2.5	0.4	5.3
			354	19 May 03	0.9	10.8	6.5	3.3	0.2	5.7
		Tilled	32	1 July 02	0.8	13.6	11.4	5	0.4	5.4
			62	31 July 02	0.7	13.8	9.2	3.6	0.4	5.6
			123	30 Sept. 02	0.7	11.5	14	2.7	0.4	5.2
			354	19 May 03	1	14.6	6.6	2.4	0.3	5.6

[a] WSP = water-soluble P.
[b] BKP = Bray and Kurtz No. 1 P.
[c] EC = electrical conductivity; EC and pH were determined in 1:1 soil:water ratio.

cores (six cores from each of three plots) representing a specific manure type and tillage condition were segmented into selected depth increments and composited. The soil samples were air-dried and analyzed for water-soluble P (WSP), Bray and Kurtz No. 1 P (BKP), NO_3-N, NH_4-N, EC, and pH. The Murphy and Riley (1962) method, which involved shaking 2 g of soil for 5 min with 20 mL of deionized water, was used to determine WSP. As an index of P availability, the BKP procedure (Bray and Kurtz, 1945) provides a relative estimate of P concentration in the soil solution that limits the growth of plants. Soil NO_3-N and NH_4-N concentrations (extracted using a 2 molar KCl solution) were measured with a flow injection analyzer using spectrophotometry (Lachat system from Zellweger Analytics, Milwaukee, Wisc.).

Rainfall Simulation Procedures

Water used in the rainfall simulation tests was obtained from a well used for irrigation. Reported nutrient concentration values represent the difference between runoff measurements and concentrations in the irrigation well water. Measured mean concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were 0.19, 0.19, 16.8, 0.04, and 16.8 mg L^{-1}, respectively. The irrigation water had a mean EC value of 0.65 dS m^{-1} and a pH of 7.67.

Rainfall simulation procedures identified by the National Phosphorus Research Project (NPRP) were employed in this study (Sharpley and Kleinman, 2003). A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall to paired plots. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the plots. To provide more uniform antecedent soil water conditions between treatments, water was first added to the plots with a hose until runoff began. The simulator was then used to apply rainfall for 30 min at an intensity of 70 mm h^{-1}. Following the initial rainfall event, plots were covered with tarps to prevent input of natural rainfall. Two additional rainfall simulation tests were then conducted for the same duration and intensity at approximately 24 h intervals.

Plot borders consisted of a sheet metal lip that emptied into a collection trough. The trough extended across the bottom of each plot and diverted runoff into aluminum washtubs.

Table 3. Analysis of variance showing the effects of tillage and time since manure application on water quality characteristics of runoff from sites on which cattle or swine manure was applied.

Variable	DP	PP	TP	NO_3–N	NH_4–N	TN	EC	pH
Cattle – PR > F								
Tillage	0.09	0.01	0.01	0.01	0.98	0.02	0.38	0.84
Time	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Tillage × time	0.03	0.01	0.01	0.01	0.40	0.01	0.07	0.17
Swine – PR > F								
Tillage	0.22	0.66	0.29	0.03	0.35	0.01	0.12	0.18
Time	0.01	0.01	0.20	0.01	0.01	0.01	0.01	0.01
Tillage × time	0.09	0.80	0.29	0.01	0.63	0.01	0.01	0.53

Table 4. Effects of tillage and time since manure application on water quality characteristics of runoff from sites on which cattle or swine manure was applied.

Manure Type	Tillage	Time (days)	Date	DP (mg L^{-1})	PP (mg L^{-1})	TP (mg L^{-1})	NO_3–N (mg L^{-1})	NH_4–N (mg L^{-1})	TN (mg L^{-1})	EC (dS m^{-1})	pH
Cattle	No-till	4	3 June 02	2.85	1.26	4.11	7.21	1.50	20.1	0.96	7.31
		32	1 July 02	2.32	1.30	3.62	7.30	0.90	19.5	0.92	7.68
		62	31 July 02	1.70	1.13	2.83	6.22	0.34	12.5	0.83	7.89
		123	30 Sept. 02	0.95	0.76	1.71	18.1	0.18	6.66	0.74	7.85
		354	19 May 03	0.50	1.13	1.63	1.57	0.07	5.39	0.8	8.13
	Till	4	3 June 02	1.46	0.69	2.15	4.73	1.30	15.1	0.91	7.37
		32	1 July 02	1.90	0.66	2.56	14.3	0.38	22.9	0.94	7.83
		62	31 July 02	1.73	0.89	2.62	11.7	1.12	20.5	0.94	7.92
		123	30 Sept. 02	1.25	0.74	1.99	26.0	0.16	16.7	0.79	7.77
		354	19 May 03	0.52	1.48	2.00	0.74	0.06	5.83	0.77	7.93
	$LSD_{0.05}$			0.27	0.24	0.38	3.39	0.40	4.76	0.07	0.13
Swine	No-till	4	3 June 02	1.14	0.59	1.73	13.6	2.33	22.9	0.85	7.31
		32	1 July 02	0.79	0.80	1.59	12.0	0.89	20.7	0.85	7.75
		62	31 July 02	0.74	0.74	1.48	11.7	0.41	16.1	0.81	7.91
		123	30 Sept. 02	0.60	0.43	1.03	17.7	0.11	5.74	0.75	7.89
		354	19 May 03	0.30	0.98	1.28	1.65	0.08	5.05	0.79	8.13
	Till	4	3 June 02	0.62	0.61	1.23	4.22	3.46	14.4	0.79	7.28
		32	1 July 02	0.67	0.73	1.40	26.4	0.61	32.9	0.90	7.74
		62	31 July 02	0.70	0.70	1.40	21.7	1.08	24.8	0.88	7.95
		123	30 Sept. 02	0.81	0.48	1.29	26.1	0.13	16.2	0.79	7.74
		354	19 May 03	0.27	0.93	1.20	1.58	0.07	5.93	0.79	8.03
	$LSD_{0.05}$				0.16		6.78		6.12	0.05	

After completion of a rainfall simulation event, the washtubs were first weighed to determine total runoff volume. The runoff was then agitated to maintain suspension of solids. Two runoff samples were obtained for water quality measurements, and two additional samples were collected for sediment analysis. Centrifuged and filtered runoff samples (obtained using No. 1 filter paper) were analyzed for DP (Murphy and Riley, 1962) and NO_3–N and NH_4–N using a Lachat system (Zellweger Analytics, Milwaukee, Wisc.). Non-centrifuged samples were analyzed for TP (Johnson and Ulrich, 1959), TN (Tate, 1994), pH, and EC. The two samples obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment content.

Data Analyses

Due to the wide variations in manure nutrient concentrations and application rates (table 1), the experimental data obtained using cattle and swine manure were analyzed separately. For a given plot, the two water quality measurements from each of the three rainfall simulation runs were treated as repeated measures. To determine differences in selected water quality parameters due to varying tillage systems and time, analysis of variance (ANOVA) was performed assuming a randomized design (table 3). A probability level <0.05 was considered significant. By using ANOVA, it is possible to determine whether there are significant differences among experimental variables. If so, the least significant difference test (LSD) was used to identify the effects of tillage and time on water quality characteristics (table 4).

Results and Discussion

It is recognized that the rainfall simulation procedures used in this study represent an extreme condition. Three consecutive high-intensity storms, each for duration of 30 min, would be unlikely to occur over a 72 h period under natural rainfall conditions. The rainfall simulation protocol used in this study allows comparison of results from selected experimental treatments. By using the same rainfall simulation and data collection procedures, participants in the NPRP and others are better able to compare and contrast experimental results obtained from their respective investigations.

In this study, mean measured runoff on the no-till cattle manure treatments was 20 mm and erosion was 0.31 Mg ha^{-1}, compared to 22 mm and 0.52 Mg ha^{-1} for tilled conditions. On the no-till swine manure treatments, mean measured runoff was 24 mm and erosion was 0.39 Mg ha^{-1}, compared to

23 mm and 0.52 Mg ha^{-1} for tilled conditions. Since runoff rates were similar between no-till and tilled conditions, the trends relating to nutrient concentration in this investigation should also be applicable to nutrient load.

P Concentrations over Time for Cattle Manure

Beef cattle produced in feedlot production systems typically receive P dietary inputs well in excess of the animals' requirements (Slatter et al., 2005). Both organic and inorganic forms of P are found in beef cattle manures. It has been estimated that organic P constitutes approximately 25% of the TP contained in feedlot manure (Eghball et al, 2002b). Soil organic P consists of labile and stable fractions (Sims and Pierzynski, 2005). The labile fractions will be mineralized after a short time and available to plants, while some of the stable fractions may remain in organic form for several years. A greater proportion of total soil P is likely to be labile for soil pH values between 5.5 and 7.0 (Reynolds, 2006). Except for the 19 May 03 sample date, pH values at the 0-5 cm depth on each of the experimental treatments were less than 7.0 (table 2). Soil pH values measured on 19 May 03 were slightly larger than 7.0 for three of the experimental treatments. At the 5-15 cm depth, soil pH values for each of the treatments were slightly less than 5.5 on selected dates.

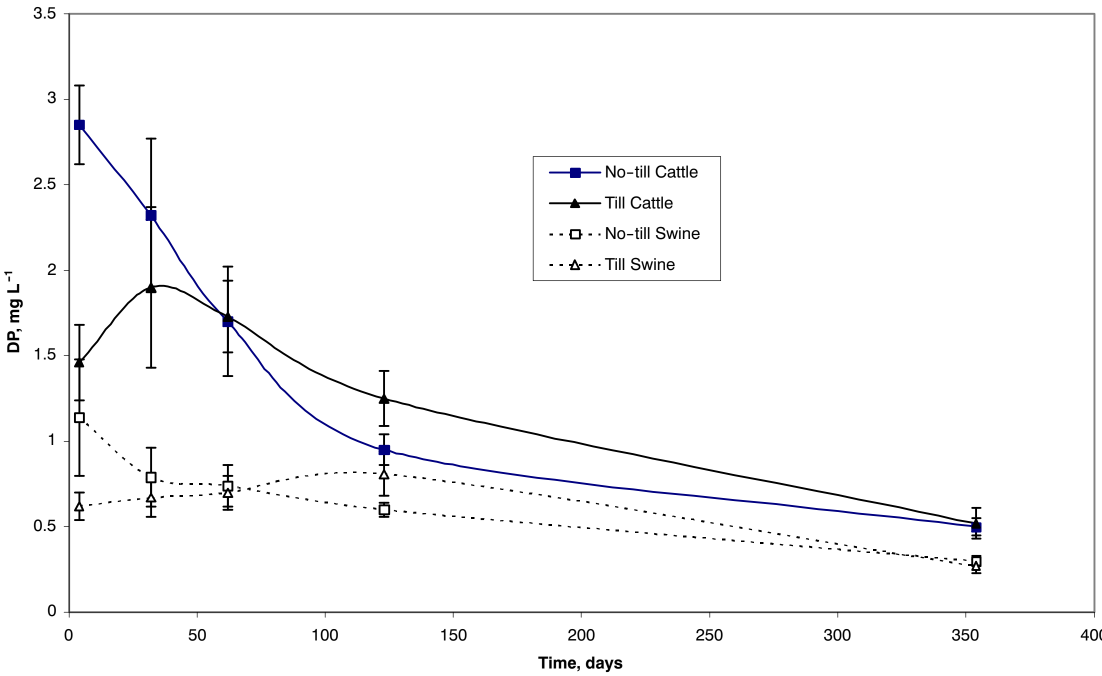

Figure 2a. Dissolved phosphorus (DP) concentrations of runoff versus time since manure application for the experimental treatments. Vertical bars represent one standard deviation of the mean value.

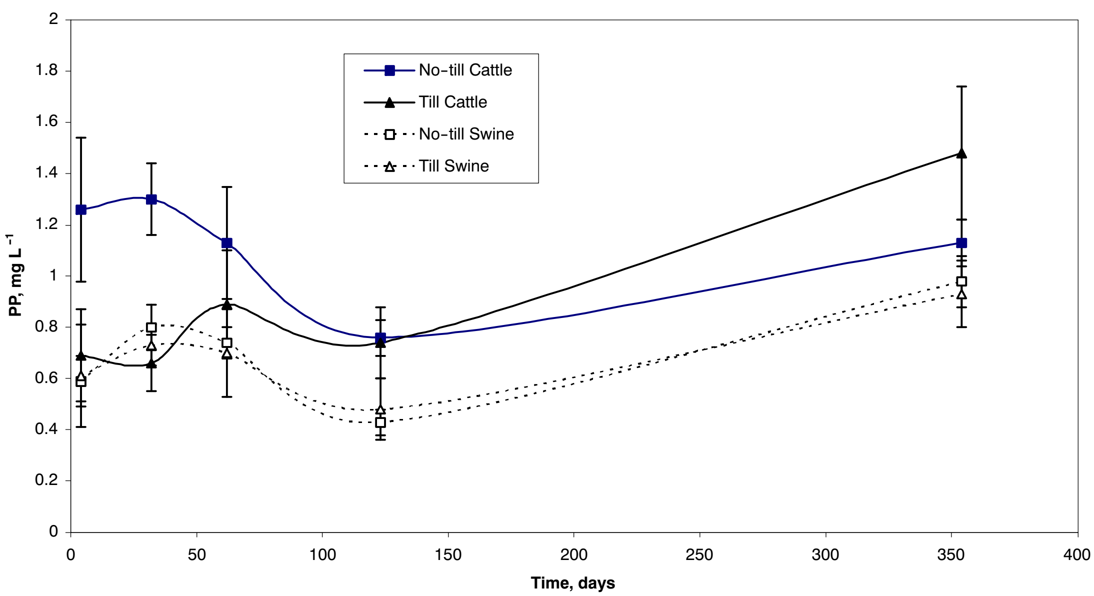

Figure 2b. Particulate phosphorus (PP) concentrations of runoff versus time since manure application for the experimental treatments. Vertical bars represent one standard deviation of the mean value.

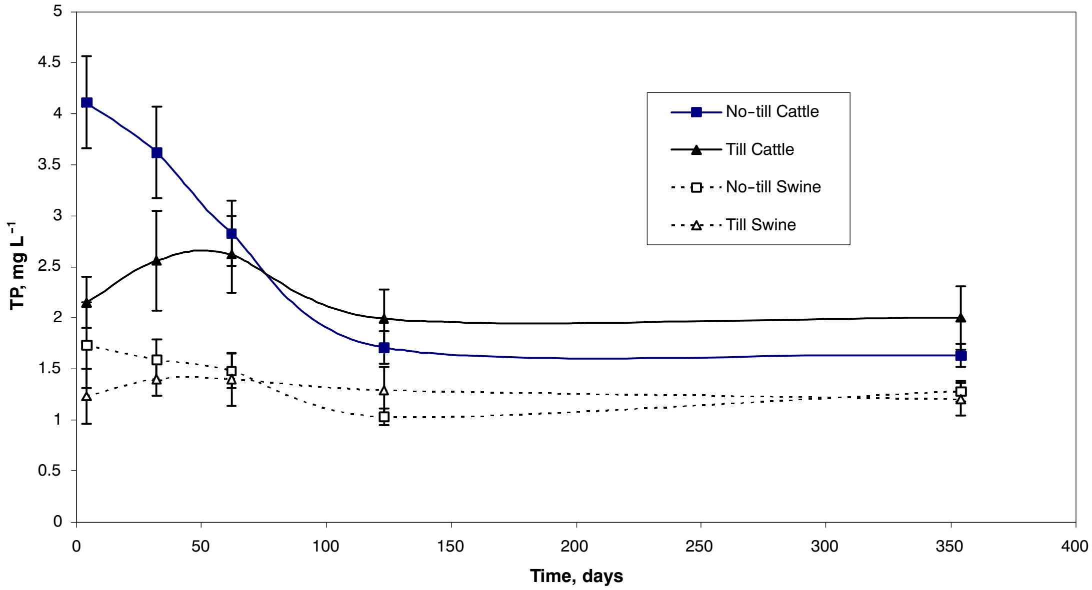

Figure 2c. Total phosphorus (TP) concentrations of runoff versus time since manure application for the experimental treatments. Vertical bars represent one standard deviation of the mean value.

Figures 2a, 2b, and 2c provide a visual representation of changes in DP, PP, and TP concentrations of runoff with time, and standard deviation values for mean P concentrations measured during a given test interval. Information is provided showing the effects of tillage and time on P constituents in runoff from areas on which cattle or swine manure had been applied.

P Concentrations Under No-Till Conditions

For the no-till cattle manure treatments, DP runoff concentrations were largest on 3 June 02 (2.85 mg L^{-1}) and then significantly declined for each subsequent test date to a value of 0.50 mg L^{-1} on 19 May 03 (fig. 2a; table 4). Eghball et al. (2002b) reported that approximately 75% of the P in cattle feedlot manure is in inorganic form, indicating that P availability following application should be high. Since total monthly precipitation was minimal during June and July 2002 (fig. 1), little DP would be expected to have infiltrated or been transported from the study site in runoff.

Concentrations of PP in runoff were calculated as the difference between measurements of TP and DP. On the no-till cattle manure treatments, concentrations of PP were significantly less on 30 Sept. 02 than the other test dates (fig. 2b; table 4). Concentrations of runoff PP are influenced both by the quantity of P attached to soil particles and the amount of sediment transported by overland flow. In general, eroded particulate materials are enriched with P when compared to surface soil because of the preferential transport by overland flow of smaller silt and clay sized soil and organic particles (Sharpley et al., 2002). Smaller sized sediment materials have a greater surface area per unit mass than larger particles and, therefore, provide a greater opportunity for attachment of P. Maintenance of surface cover and associated reduction in soil loss potential is attributed to the relatively uniform PP concentrations of runoff measured on the no-till cattle manure treatments.

Concentrations of TP in runoff consistently declined on the no-till cattle manure treatments from 4.11 mg L^{-1} on 3 June 02 to 1.63 mg L^{-1} on 19 May 03 (fig. 2c; table 4). Significant differences in runoff TP concentrations were identified among the first four test dates. However, no significant differences in runoff TP concentrations were found between the final two test dates. The previous transport of P by rainfall and on-going mineralization would have substantially reduced the amount of inorganic P in manure available for transport by 30 Sept. 02 (123 days after manure application).

P Concentrations Under Tilled Conditions

The largest DP concentrations on the treatments where cattle manure was incorporated occurred on 1 July 02 (1.90 mg L^{-1}), and then runoff DP concentrations consistently declined during the remainder of the investigation (fig. 2a; table 4). Lack of precipitation (fig. 1) may have been responsible for the relatively small WSP and BKP values (7.6 and 96.1 mg kg^{-1}) measured for the samples collected at the 0-5 cm soil depth on 1 July 02 (table 2). Mineralization of organic P in the incorporated cattle manure is attributed to the increased WSP and BKP measurements obtained on the final three sampling dates.

No significant differences in PP concentrations of runoff were found among measurements obtained on the tilled cattle manure treatments during the first four test periods (fig. 2b; table 4). The largest PP values were measured on the final test date, nearly a year after manure application. Decomposition of crop residue materials over the winter and spring months and associated increase in soil loss potential on the treatments that had initially been tilled could have been responsible for the significantly larger PP values measured on 19 May 03.

The largest runoff TP concentrations for the tilled cattle manure treatments were measured for the test dates initiated on 1 July 02 and 31 July 02 (2.56 and 2.62 mg L^{-1}) (fig. 2c; table 4). No significant differences in concentrations of TP in runoff were found among the other test dates. A more uniform release of inorganic P is expected over time under tilled conditions, since P in manure is readily attached to soil particles. Gilley and Eghball (2002) found that after four years of corn production following the last application of beef cattle compost, the P content of surface soils was still elevated.

Tillage Effects on P Concentrations

Runoff concentrations of DP, PP, and TP for the tests initiated on 3 June 02 and 1 July 02 were significantly greater on the no-till than the tilled plots (table 4). No significant differences in TP concentrations in runoff were found between no-till and tilled conditions on the final three test dates. Eghball et al. (2000), working on plots containing corn residue, also found that DP, PP, and TP concentrations in runoff resulting from simulated rainfall soon after the application of cattle manure were greater on the no-till than the tilled treatments. Eghball and Gilley (1999) found that runoff concentrations of DP were significantly greater under no-till conditions when cattle manure was applied to sites containing sorghum and wheat residue.

Overland flow may come in contact with all of the cattle manure applied on no-till areas, providing increased opportunity for leaching. In contrast, much of the applied manure is incorporated into the soil profile during the tillage process and is, therefore, not directly in contact with overland flow. Tillage also serves to reduce the amount of crop residue on the soil surface.

Areas with substantial surface cover have larger hydraulic roughness coefficients (Gilley et al., 1991). As a result, overland flow runoff velocities may be reduced on sites with substantial residue cover. In addition, water is stored on upland areas in small ponds created by crop residue (Gilley and Kottwitz, 1994). A large number of ponds may create a substantial volume of water.The reduced runoff velocity and ponding of water caused by crop residue could have increased leaching of P from the cattle manure applied to the no-till sites.

Bundy et al. (2001), in their studies of tillage and dairy manure application effects on P losses from corn production systems, showed that tillage to incorporate manure generally lowered DP runoff concentrations but increased TP concentrations due to increased sediment load. Research on conservation tillage systems has shown that stratification of P at the soil surface can increase DP runoff losses over time. However, reduced tillage has also been demonstrated to decrease PP runoff losses (Sims and Kleinman, 2005).

A large relatively rapid input of inorganic P would be expected at the 0-5 cm depth on the no-till cattle manure treatments. As a result, values of WSP and BKP were substantially larger on the no-till than the tilled treatments for the 1 July 02 sampling date (table 2). However, less mineralization of P would be expected when cattle manure was left on the soil surface under no-till conditions. In contrast, incorporation of the cattle manure during tillage would disperse more of the nutrients within the soil, helping to conserve N and P and provide a greater opportunity for mineralization.

P Concentrations over Time for Swine Manure

Swine diets are often over-supplemented with P, which greatly increases P excretion, and most of the P in cereal grains and oilseed meals is in the form of indigestible phytic acid that is excreted in the manure (Cromell, 2005). It has been estimated that approximately 3% of the dry matter in swine manure contains P (Sweeten, 1992), and 91% of the TP in swine manure is in an inorganic form (Sharpley and Moyer, 2000). Thus, excessive application of P often results when swine manure is applied to meet N plant requirements (Reynolds, 2006).

The amount of P applied on the swine manure treatments (37 kg ha^{-1}) was substantially less than the quantity added to the cattle manure plots (203 kg ha^{-1}) (table 1). This difference was caused by variations in the N:P ratio for cattle and swine manure, and application rates determined assuming 40% N availability for beef cattle manure (Eghball and Power, 1999) and 70% N availability for swine manure (Gilbertson et al., 1979). As a result, concentrations of DP, PP, and TP in runoff from the swine manure treatments, in general, were less than the cattle treatments (figs. 2a, 2b, and 2c; table 4).

P Concentrations Under No-Till Conditions

Concentrations of DP in runoff from the no-till swine manure treatments were largest on 3 June 02 (1.14 mg L^{-1}). DP concentrations then declined for each subsequent test date to a value of 0.30 mg L^{-1} on 19 May 03 (fig. 2a; table 4). The availability of P should have been relatively high for the swine manure treatments, since approximately 91% of the total P in swine manure is in inorganic form (Sharpley and Moyer, 2000). Gilley et al. (2001) found that changing swine diets to reduce the P content of manure did not significantly affect the total amount of DP transported in runoff, when simulated rainfall was applied soon after manure application.

Measurements of WSP at the 0-5 cm soil depth of the no-till swine manure treatments varied little among sampling dates (table 2), and the values obtained on 31 July 02 and 30 Sept. 02 were similar to those measured before manure application (baseline values). In comparison, BKP measurements at the 0-5 cm depth were largest on 1 July 02 and 31 July 02, and values obtained on the last two sampling dates were similar to baseline measurements. In summary, the total amount (37 kg ha^{-1}) and concentration (1.01 g kg^{-1}) of P applied in swine manure during this study was relatively small (table 1), and thus the quantity of P infiltrating into the soil profile under no-till conditions, in general, was minimal.

No well-defined trend was apparent describing changes in runoff PP concentrations over time on the no-till swine manure treatments (fig. 2b; table 4). The largest PP concentration (0.98 mg L^{-1}) was measured on 19 May 03. The relatively large PP runoff concentrations measured on the final test date may have been influenced by a reduction in surface cover over the winter and spring periods resulting from residue decomposition and the associated increase in soil loss potential.

Concentrations of TP in runoff from the no-till swine manure treatment were not significantly affected by tillage condition or time since manure application (table 3). The largest TP runoff concentration for the no-till swine manure treatment (1.73 mg L^{-1}) was measured on 3 June 02 (table 4).

P Concentrations Under Tilled Conditions

Tillage condition or time since manure application did not significantly affect concentrations of TP in runoff from the tilled swine manure treatment (table 3). On the tilled swine manure treatment, DP runoff concentrations were similar among the first four test dates (fig. 2a; table 4). In contrast, the largest concentrations of PP in runoff occurred on the final test date. Concentrations of TP in runoff were similar throughout the study (fig. 2c; table 4).

Measurements of WSP at the 0-5 cm soil depth of the swine manure treatments on the first three dates following manure application were similar to the baseline value (table 2). BKP measurements were similar throughout the study. The relatively small amounts of P applied in the swine manure (table 1) are attributed to minimal changes in soil P concentrations.

Tillage Effects on P Concentrations

Concentrations of DP in runoff were larger under no-till conditions for the tests initiated on 3 June 02, while larger DP values were obtained under tilled conditions on the 30 Sept. 02 test date (fig. 2a; table 4). However, there were no significant tillage induced differences in runoff concentrations of DP, PP, or TP for the swine manure treatments (table 3).

TP concentrations on the no-till treatments were greater for the tests beginning on 3 June 02 (fig. 2c; table 4). However, TP runoff values were similar between no-till and tilled conditions for the other four test dates. A larger quantity of P would be expected to be available for transport for the simulation tests conducted soon after manure application under no-till conditions. However, tillage appeared to have little effect on reducing TP runoff concentrations from the swine manure treatments during the remainder of the study.

Tabbara (2003) found that incorporation of swine manure by disking 24 h before applying simulated rainfall at an intensity of 64 mm h^{-1} for 1.5 h significantly reduced flow-weighted concentrations of DP and TP. Similar results were found in the present study when rainfall simulation tests were conducted approximately 48 h after incorporation of swine manure by disking.

A rainfall simulator operating at an intensity of 64 mm h^{-1} was used by Daverede et al. (2004) to apply rainfall to plots where low (39.4 kg P ha^{-1}) and high (78.6 kg P ha^{-1}) rates of swine manure were either surface-applied or incorporated at a 10 cm depth using an injector with disk sweeps. Simulated rainfall was added one month and six months after initial manure application until runoff occurred for a 30 min period. Injection of the swine manure significantly reduced concentrations of DP and TP during rainfall simulation tests conducted one month after manure application at both low and high application rates. However, for the rainfall simulation tests conducted six months after the addition of manure, tillage did not significantly affect DP concentrations of runoff where manure was applied at the lower rate. After the six-month test interval, no significant differences in TP concentrations were found between the surface-applied and manure injection treatments at either low or high application rates.

In contrast to the results reported by Daverede et al. (2004), no significant tillage induced differences in DP or TP runoff concentrations were found after a one-month period in the present study. The difference in results between the two investigations may have been caused by the method used to incorporate the swine manure. Daverede et al. (2004) used an injector with disk sweeps operating at a 10 cm depth, while a disk was used in the present study. The disk may have allowed more manure to remain near the soil surface following tillage and, therefore, provided a greater opportunity for interaction between the overland flow and swine manure.

N Concentrations over Time for Cattle Manure

Significant amounts of N, a major component of protein, are contained in beef cattle rations. The quantity of N in beef cattle manure has been estimated as approximately 4% of total dry matter (Sweeten, 1992). The amount of N available from manure applied to a growing crop includes the inorganic content of manure (NH_4-N and NO_3-N) plus the amount of organic N (complex molecules associated with undigested food) that is mineralized following application (Reynolds, 2006). Mineralization of organic nutrients contained in manure is influenced by the composition of the manure and soil characteristics, including the pattern of drying and wetting cycles, temperature, and water content (Cabrera et al., 2005). It is estimated that the organic N in cattle feedlot manure mineralized the first year after application is 30%, while the TN available is 40% (Eghball, 2000). Concentrations of NO_3-N in beef cattle manure are typically low, but manure N can be transformed to NO_3-N through oxidation of NH_4-N after land application, a process know as nitrification (Reynolds, 2006).

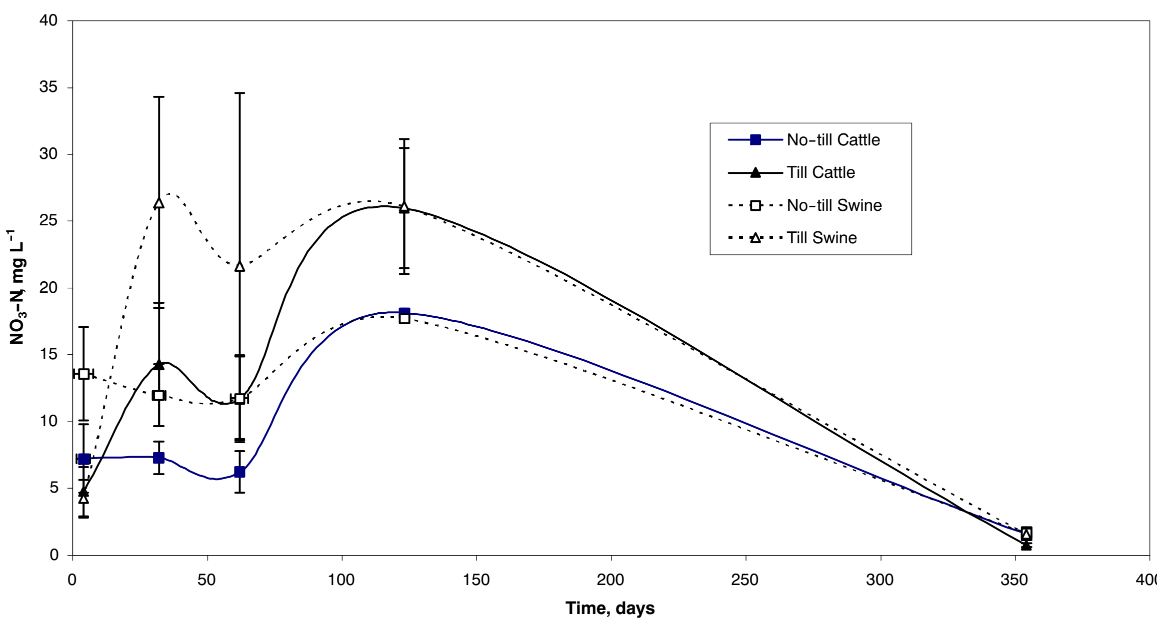

Figure 3a. NO_3-N concentrations of runoff versus time since manure application for the experimental treatments. Vertical bars represent one standard deviation of the mean value.

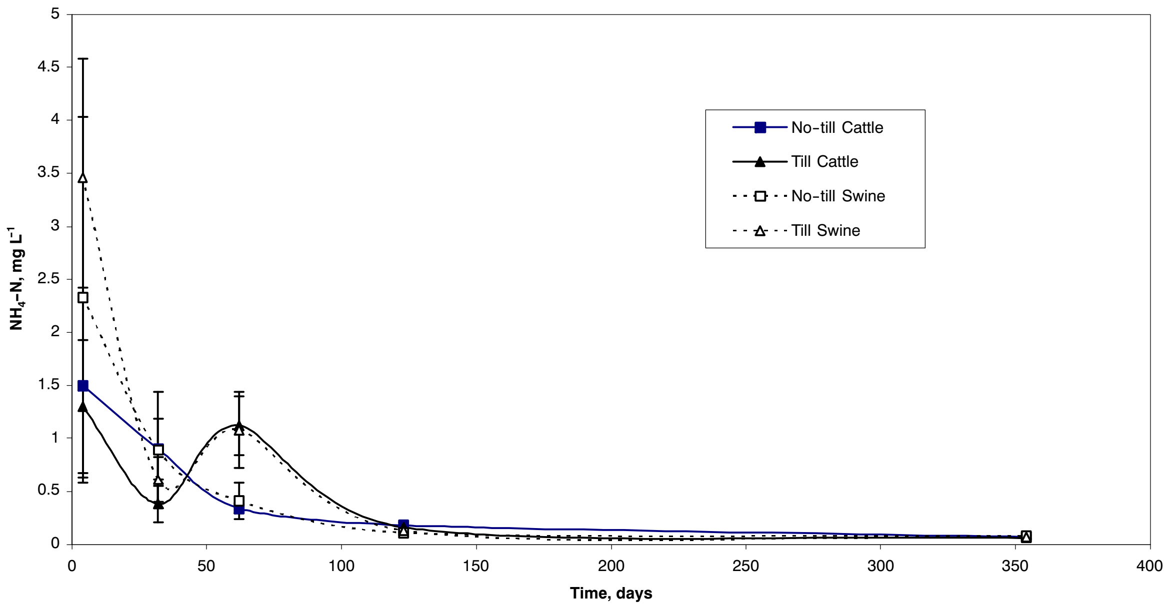

Figure 3b. NH_4-N concentrations of runoff versus time since manure application for the experimental treatments. Vertical bars represent one standard deviation of the mean value.

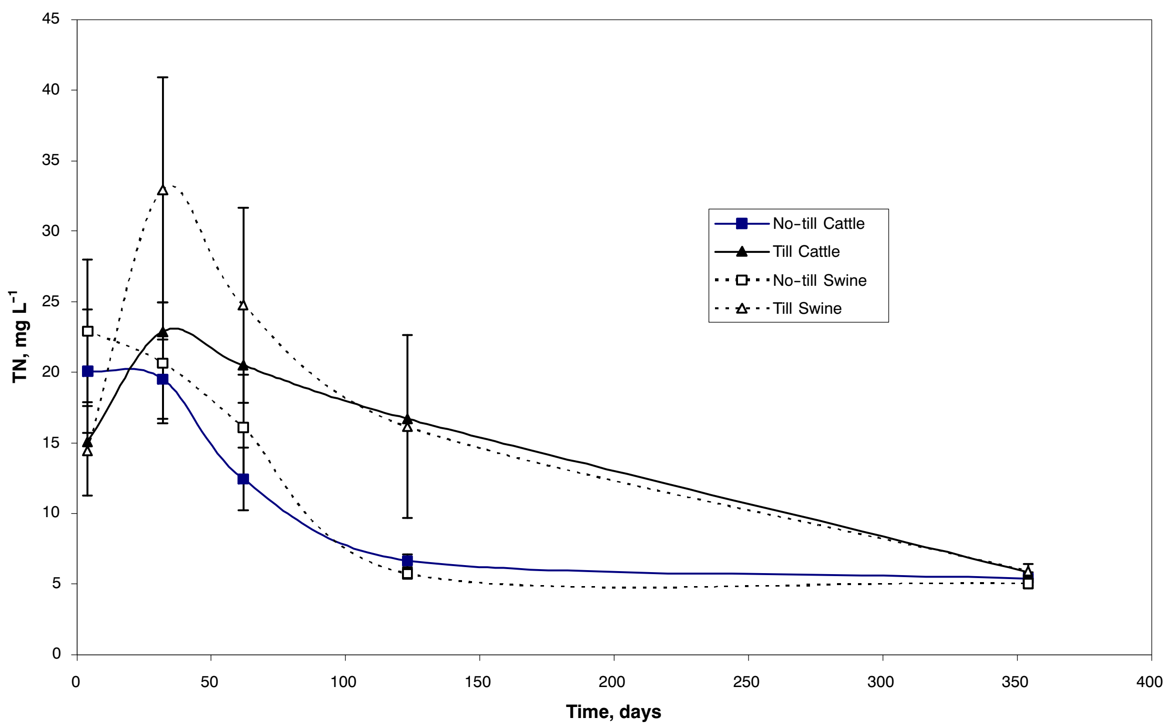

Figure 3c. Total nitrogen (TN) concentrations of runoff versus time since manure application for the experimental treatments. Vertical bars represent one standard deviation of the mean value.

N Concentrations Under No-Till Conditions

Since the amount of NO_3-N contained in beef cattle manure is minimal (table 1), NO_3-N in runoff would be expected to result from mineralization of organic constituents. For the no-till cattle manure treatments, no significant differences in runoff NO_3-N concentrations were measured among the first three test dates (fig. 3a; table 4). However, for the test date beginning on 30 Sept. 02 (13 days following corn harvest), the NO_3-N runoff concentrations significantly increased. Significant increases in NO_3-N concentrations of runoff on the cattle manure treatments also occurred on the same test date under tilled conditions.

Leaching of nutrients from the recently harvested corn crop may have caused the increased NO_3-N concentrations in runoff measured on 30 Sept. 02 from both the no-till and tilled cattle manure treatments. Crop residues on the soil surface subjected to rainfall leaching have been found to be a significant source of soluble nutrients in agricultural runoff (Schreiber, 1985). The fraction of water-soluble mass in plant material that was leached under rainfall was reported to increase for NO_3-N, decrease for NH_4-N, and remain constant for PO_4-P, as residue decomposed (Havis and Alberts, 1993). Nutrient concentrations in leachate were found by Schreiber (1999) to be greater at lower rainfall intensities and higher corn residue loading rates. NO_3-N concentrations in leachate resulting from individual storms rapidly decreased with either time or cumulative leachate volume to a near-constant value. Leachate from corn residue was also found to contain significant amounts of PO_4-P and NH_4-N (Schreiber, 1999). Thus, crop residue materials appear to have the potential to influence the N and P content of runoff through leaching and sorption (Cermak et al., 2004).

The relatively small amount of NO_3-N (1.57 mg L^{-1}) measured in runoff on the final test date (19 May 03) (fig. 3a; table 4) probably resulted from the leaching of NO_3-N originally located near the surface to greater soil depths. The amount of NO_3-N measured on 19 May 03 at the 0-5 cm depth of the no-till cattle manure treatments (7.2 mg kg^{-1}) was approximately the same as the baseline level (table 2).

The concentration of NH_4-N in cattle manure at the time of application (table 1) was relatively small (0.27 g kg^{-1}). Therefore, substantial bacterial decomposition appeared to have occurred soon after the addition of cattle manure to cause the 1.50 mg L^{-1} of NH_4-N (the largest value obtained for any of the test dates) measured on 3 June 02 (fig. 3b; table 4). The amount of NH_4-N found at the 0-5 cm soil depth on 1 July 02 was 12.1 mg kg^{-1} (table 2), but measurements near baseline values were obtained for the other test dates. Significant reductions in NH_4-N runoff concentrations were found among the first three study dates (table 3). On the final test date, mean NH_4-N concentrations in runoff on the no-till cattle manure treatments were reduced to 0.07 mg L^{-1}.

Substantial concentrations of TN were measured in runoff on the no-till cattle manure treatments on 3 June 02, 1 July 02, and 31 July 02 (fig. 3c; table 4). This time interval corresponds with the period of rapid corn growth and substantial N uptake. On both the no-till and tilled cattle manure treatments, TN concentrations of runoff measured on 30 Sept. 02 (13 days following corn harvest) were less than the NO_3-N concentrations obtained for the same test date. The reason for this discrepancy is not known.

N Concentrations Under Tilled Conditions

Significant differences in runoff NO_3-N concentrations were found among several test dates on the tilled cattle manure treatments (fig. 3a; table 4). Differences in NO_3-N concentrations among test dates were attributed to varying rates of N mineralization, with the exception of the 30 Sept. 02 test period. As was discussed previously for the no-till cattle manure treatments, NO_3-N leaching from recently harvested corn was thought to have caused the relatively large NO_3-N concentration measured for the 30 Sept. 02 test period (26.0 mg L^{-1}). Leaching of NO_3-N over the winter and spring months is credited for the relatively small (9.8 mg kg^{-1}) NO_3-N value obtained on the final test date for the 0-5 cm soil depth (table 2).

Concentrations of NH_4-N in runoff for the tilled cattle manure treatments ranged from 1.30 mg L^{-1} on 3 June 02 to 0.06 mg L^{-1} for the tests conducted on 19 May 03 (fig. 3b; table 4). Although significant differences in NH_4-N concentrations were measured among test dates (table 3), no consistent trends between consecutive test periods were apparent. Concentrations of NH_4-N in runoff were reduced substantially on 30 Sept. 02 and 19 May 03, probably as a result of substantial reductions in the mineralization of organic N. As was the case under no-till conditions, NH_4-N content at the 0-5 cm soil depth was minimal for the 30 Sept. 02 and 19 May 03 test dates (table 2).

The largest quantity of TN measured in runoff from the tilled cattle manure treatments (22.9 mg L^{-1}) occurred on 1 July 02 (fig. 3c; table 4). Under tillage conditions, it may have taken a few days for the mineralization process to progress, especially with the lack of precipitation (fig. 1). Total N measured in runoff on the tilled cattle manure treatments consistently decreased during the study to a value of 5.83 mg L^{-1} measured on 19 May 03.

Tillage Effects on N Concentrations

No significant differences in NO_3-N runoff concentrations were found between no-till and tilled conditions for the tests initiated on the cattle manure treatments on 3 June 02 and 19 May 03 (fig. 3a; table 4). However, for the tests conducted on the other three test dates, NO_3-N runoff concentrations were significantly greater under tilled conditions. Except for the 30 Sept. 02 test date, soil NO_3-N values measured among respective test dates at the 0-5 and 5-15 cm depths, in general, were similar under no-till and tilled conditions (table 2). Movement of NO_3-N to the 5-15 cm soil depth was apparent on 30 Sept. 02 under both no-till and tilled conditions. The substantial rainfall occurring in July and August 2002 (fig. 1) and the leaching of NO_3-N from crop residues following corn harvest on 17 Sept. 2002 are attributed to NO_3-N movement to the 5-15 cm soil depth.

Runoff NH_4-N concentrations (fig. 3b; table 4) were significantly greater under no-till conditions for the test interval beginning on 1 July 02 (0.90 mg L^{-1}). However, significantly larger concentrations of NH_4-N were found on the tilled treatments on the 31 July 02 test date (1.12 mg L^{-1}). The largest NH_4-N content measured on the no-till treatments at the 0-5 cm soil depth (12.1 mg kg^{-1}) occurred on 1 July 02, while 15.5 mg kg^{-1} of NH_4-N was measured on the tilled treatments on 31 July 02. Tillage did not significantly influence NH_4-N runoff concentrations from the cattle manure treatments on the other test dates (table 3).

On the 3 June 02 test date, concentrations of TN in runoff from the cattle manure treatments (fig. 3c; table 4) were significantly greater on the no-till treatments (20.1 mg L^{-1}), while TN concentrations were larger on the tilled treatments for the tests initiated on 31 July 02 (20.5 mg L^{-1}) and 30 Sept. 02 (16.7 mg L^{-1}). Between 3 June 02 and 30 Sept. 02, TN concentrations in runoff declined substantially under no-till conditions but were similar on the tilled treatments.

N Concentrations over Time for Swine Manure

Swine manure usually contains relatively large concentrations of N, estimated at 4.7% of dry matter (Sweeten, 1992). Swine diets are usually relatively high in crude proteins due to the large amounts of amino acids required for swine growth. Much of the N from the amino acids that is in excess of swine requirements is converted into urea and excreted in the urine. The dietary protein is also not completely digested, resulting in approximately 15% to 20% of the dietary N passing out of the swine in the feces (Cromwell, 2005). The amount of organic N in swine manure mineralized the first year after application is approximately 40%, while total N availability has been estimated at 90% (Hatfield et al., 1998).

N Concentrations Under No-Till Conditions

The NO_3-N content of swine manure used in this study prior to application was minimal (table 1). However, NO_3-N runoff concentrations on the no-till swine manure treatments were similar for the 3 June 02 (13.6 mg L^{-1}), 1 July 02 (12.0 mg L^{-1}), and 31 July 02 (11.7 mg L^{-1}) test dates, indicating a rapid and continuous mineralization of organic N (fig. 3a; table 4). The NO_3–N content of soil measured at the 0-5 cm depth of the no-till swine manure treatments on 1 July 02 (57.3 mg kg^{-1}) and 31 July 02 (69.1 mg kg^{-1}) was also relatively large (table 2). The largest NO_3–N runoff concentration on the no-till swine manure treatments (17.7 mg L^{-1}) was measured on the 30 Sept. 02 sampling date, and was similar to the values found for cattle manure on this same date under no-till conditions (18.1 mg L^{-1}).

The relatively large NO_3–N runoff concentration identified on 30 Sept. 02 is again attributed to substantial rainfall and NO_3–N leaching from recently harvested corn. The relatively small concentration of NO_3–N measured in runoff on 19 May 03 (1.65 mg L^{-1}) is thought to have been caused by the leaching of NO_3–N from near the soil surface over the winter and spring months. Soil NO_3–N content obtained at the 0-5 cm depth on 19 May 03 (7.2 mg kg^{-1}) is near the baseline value (table 2).

A substantial amount of NH_4–N (4.07 mg kg^{-1}) was contained in the swine manure (table 1). Significant differences in NH_4–N runoff concentrations were found over time (table 3). The 2.33 mg L^{-1} of NH_4–N measured in runoff on 3 June 02 for the no-till swine manure treatment was significantly larger than that obtained for the other test dates (fig. 3b; table 4). The consistent decline in measured NH_4–N concentrations throughout the study on the no-till swine manure treatments is attributed to nitrification and/or volatilization of NH_4–N. The NH_4–N content of soil at the 0-5 cm depth rapidly declined from 25.2 mg kg^{-1} on 1 July 02 to values near the baseline level on 30 Sept. 02 and 19 May 03 (table 2).

The largest concentrations of TN in runoff on the no-till swine manure treatments occurred on 3 June 02 (22.9 mg L^{-1}) (fig. 3c; table 4). Values of TN consistently declined for the remainder of the study and were minimal on 30 Sept. 02 (5.74 mg L^{-1}) and 19 May 03 (5.05 mg L^{-1}). The reduced TN concentrations would imply that most of the available N in the swine manure was utilized for crop growth during the growing season, and by 30 Sept. 02 mineralization of organic nitrogen was significantly reduced. However, TN runoff concentrations obtained on 30 Sept. 02 (13 days following corn harvest) were less than NO_3–N concentrations for the corresponding test period on both the no-till and tilled cattle manure treatments. Again, the reason for this discrepancy is not known.

N Concentrations Under Tilled Conditions

The relatively small NO_3–N runoff concentrations measured on the tilled swine manure treatments on 3 June 02 (4.22 mg L^{-1}) imply that incorporation of the swine manure might have partially delayed the nitrification process (fig. 3a; table 4). Concentrations of NO_3–N in runoff significantly increased on 1 July 02, 31 July 02, and 30 Sept. 02, varying from 21.7 to 26.4 mg L^{-1}. The 1.58 mg L^{-1} of NO_3–N runoff obtained on 19 May 03 is attributed to NO_3–N leaching into the soil over the winter and spring periods. The NO_3–N soil content measured at the 0-5 cm depth of the tilled swine manure treatments were also relatively large on 1 July 02, 31 July 02, and 30 Sept. 02, ranging from 37.2 to 47.7 mg kg^{-1} (table 2). The NO_3–N content of soil measured at the 0-5 cm soil depth on 3 June 02 (7.57 mg kg^{-1}) was similar to the baseline value.

The largest NH_4–N runoff concentrations on the tilled swine manure treatments (3.46 mg L^{-1}) occurred on 3 June 02 (fig. 3b; table 4). Concentrations of NH_4–N in runoff then significantly declined for the remainder of the study. Soil NH_4–N content measured at the 0-5 cm depth on the tilled swine manure treatments, in general, were relatively small varying from 2.3 to 11.0 mg kg^{-1} on the four test dates (table 2).

Total N runoff concentrations under tilled conditions for the swine manure treatments were 14.4 mg L^{-1} on 3 June 02 and 32.9 mg L^{-1} on 1 July 02, the largest values measured during the study period (fig. 3c; table 4). For the remaining three test dates, TN runoff concentrations declined significantly.

Tillage Effects on N Concentrations

For the 1 July 02, 31 July 02, and 30 Sept. 02 test dates, NO_3–N runoff concentrations were significantly greater on the till than the no-till swine manure treatments (fig. 3a; table 4). However, NO_3–N content at the 0-5 cm soil depth was substantially larger under no-till conditions on 1 July 02 and 31 July 02 (table 2). For each of the test dates, soil NO_3–N values were similar at the 5-15 cm soil depth under no-till and tilled conditions.

Concentrations of NH_4–N in runoff from the swine manure treatments were significantly greater under tilled than no-till conditions on 3 June 02 (fig. 3b; table 4). However, for the other test dates, NH_4–N runoff concentrations were generally minimal. Tillage did not significantly influence NH_4–N runoff concentrations (table 3). The NH_4–N content measured at the 0-5 cm soil depth was substantially less on the tilled than the no-till swine manure treatments (table 2).

Concentrations of runoff TN for the swine manure treatments were significantly larger on the no-till than the tilled treatments on 3 June 02 (fig. 3c; table 4). However, for the next three test dates, TN runoff concentrations were significantly larger on the tilled treatments. Incorporation helped to conserve N contained in the swine manure. Values of runoff TN measured on 19 May 03 were similar on the no-till and tilled cattle and swine and manure treatments, and probably represent baseline values. Nicolaisen et al. (2007) found that the amount of residue on the soil surface did not significantly affect nutrient concentrations in runoff on plots containing residue and swine manure and cropped under no-till conditions.

Measurements of EC and pH

EC and pH for the Cattle Manure Treatments

Total salt concentration can be used to estimate EC. Manure may contain high levels of soluble salts that may be detrimental to crop growth if applied at high enough rates (Reynolds, 2006). In this study, the EC of the cattle manure at the time of application was 12.0 dS m^{-1}, while the pH was 8.1 (table 1). When organic residues have been mineralized but the resultant nitrates have not been taken up by plants, higher EC and lower pH values may result (Smith and Doran, 1996).

Calcium carbonate ($CaCO_3$) is commonly added to cattle diets as a source of calcium, and the recommended level is 7 g kg^{-1} of ration (Klemesrud et al., 1998). Much of the $CaCO_3$ is excreted in manure. The pH of manured soils can be increased (become more basic) as a result of land application (Eghball, 1999). For soils requiring lime application, the amount of $CaCO_3$ required could be reduced on fields where manure has been applied.

Larger EC values and lower pH measurements (along with increased nitrate values) are expected when organic residues have been mineralized but plants have not taken up the resultant nitrates. The opposite condition appears to have occurred for the cattle manure treatments. In general, EC values of runoff decreased and pH measurements increased during the year following manure application. A compounding and apparently more important factor in this study was the presence of $CaCO_3$ in the manure. The lower EC and greater pH values measured in runoff over time are attributed to the addition of $CaCO_3$ to the cattle ration.

EC and pH for the Swine Manure Treatments

The EC of the swine manure at the time of application (table 1) was 25.0 dS m^{-1}, while the pH was 6.8. Larger EC and lower pH values may result from mineralization of swine manure. The diets of growing swine also contain $CaCO_3$ added at a rate of approximately 9 g kg^{-1} of ration (Reese et al., 1995). Following land application of swine manure, the pH of manured soils can increase as a result of $CaCO_3$ contained in the manure.

In general, tillage and time since manure application had little effect on runoff EC values on the swine manure treatments. Significant temporal variations in pH measurements were found among dates for the swine manure treatments (table 3). The addition of $CaCO_3$ in the swine manure is attributed to the higher pH values measured over time. There were no significant tillage-induced differences in pH measurements of runoff among study dates (table 3).

Conclusions

Consistent reductions in runoff concentrations of DP, TP, NH_4-N, and TN were measured over time on the no-till cattle treatments. Tillage significantly reduced concentrations of DP, PP, and TP for approximately one month on the treatments where cattle manure was applied. Incorporation of cattle manure by disking did not significantly reduce runoff concentrations of P constituents for the remainder of study.

Consistent reductions in DP, TP, NH_4-N, and TN concentrations in runoff were measured over time on the no-till swine manure treatments. Runoff concentrations of DP, TP, NO_3-N, and TN were significantly reduced by tillage for the rainfall simulation tests initiated four days following swine manure application. Incorporation of the swine manure by disking did not reduce nutrient concentrations of runoff during the other four test dates.

With the exception of PP, minimum concentrations of nutrients in runoff generally occurred approximately one year after manure addition. The relatively large PP runoff concentrations measured on the final test date may have been influenced by a reduction in surface cover over the winter and spring periods resulting from residue decomposition and the associated increase in soil loss potential.

In general, the largest runoff NO_3-N concentrations occurred 13 days following corn harvest on 30 Sept. 02. The leaching of N from corn residue is thought to have caused the increase in measured NO_3-N concentrations of runoff.

Under both no-till and tilled conditions on the cattle and swine manure treatments, pH runoff values were found to increase during the study. The addition of $CaCO_3$ to the rations of the beef cattle and swine is thought to have caused the increase in pH runoff measurements.

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