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ABSTRACT. *The P content of swine manure can be reduced through the addition of feed supplements or the use of selected corn hybrids. This study was conducted to compare interrill runoff losses of P and N from three soils following the application of swine manure obtained from selected diets. The soils used in this investigation included a Hersh sandy loam, Pierre silty clay, and Sharpsburg silt loam. Simulated rainfall was applied during both initial and wet runs to a soil pan on which swine manure produced from low phytate corn (LPC), phytase added to the diet (PHY), or a traditional corn diet (TCD) was added. Additional experimental treatments included inorganic fertilizer and an untreated check. For the initial rainfall simulation run, concentrations of dissolved P, bioavailable P, and Total P were greater for the fertilizer treatment than any of the manure treatments. Use of manure from a LPC diet generally did not result in a reduction in N and P concentrations in runoff when compared with the TCD. Concentrations and total amounts of nutrients transported in runoff were affected by soil type. Changing the TCD to LPC and PHY diets to reduce the P content of manure did not significantly affect the total amounts of DP, BAP, or Total P transported in runoff, when simulated rainfall was applied soon after manure application.*

Keywords. *Manure management, Manure runoff, Nitrogen movement, Nutrient losses, Phosphorus, Swine manure, Water quality.*

Manure contains nutrients that are essential for plant growth and organic matter that can improve soil chemical and physical properties. Mielke and Mazurak (1976) determined that the addition of manure increased soil aggregation, bulk density, and infiltration. Organic C, total N, and potentially mineralizable N in the 0 to 7.5 cm depth of manure–amended soils were found by Fraser et al. (1988) to be 22% to 40% greater than in non–manured soils receiving chemical fertilizer. Sommerfeldt et al. (1988) concluded that the greatest rate of increase in soil organic matter and N content occurs the first few years after the addition of manure. The benefits to soil from manure application are influenced by the original soil properties (Lax, 1991). Paustian et al. (1992) found that an annual addition of manure over a 19–year period increased soil C content by approximately 30%. Soil organic matter, available P, and exchangeable Ca, K, and Mg increased on a loam and sandy loam soil having the largest manure application rate (Vitosh et al., 1973).

Mitchell and Gunther (1976) found that the application of liquid swine manure to small laboratory soil pans reduced runoff and erosion rates. In a laboratory study on several soils in India to which cattle manure was added, Chandra and De (1982) concluded that erosion did not change on soils incubated for 15 days following manure addition, while erosion decreased on soils 30 days following manure application. Westerman et al. (1983) determined that manure characteristics, loading rates, incorporation, and the time between application and the first rainfall influenced soil loss rates from laboratory test plots on which poultry litter had been applied. Gilley et al. (1999) determined that the long–term application of beef cattle manure to a sandy loam soil did not significantly influence erosion from a 1–m^2 plot area under simulated rainfall conditions. However, runoff and soil loss values from natural precipitation events were reduced substantially when manure was applied to plots with slope lengths varying from 21 to 24 m (Gilley and Risse, 2000).

If not utilized for plant growth, the land application of manure may cause environmental problems. Elevated soil P levels usually result from the long–term application of manure to soils at rates in excess of crop nutrient requirements (Sharpley et al., 1994; Sims, 1993). Eghball and Power (1999) found that the application of manure to meet crop N requirements resulted in significant P build–up in the soil. The concentration of P in runoff is typically influenced by manure or fertilizer application rate and soil P test level (Daniel et al., 1994; Pote et al., 1996). Sharply et al. (1985) found NO_3–N concentration of the top 0 to 50 mm of soil did not significantly affect the NO_3–N concentration of runoff. However, dissolved P and Total N content of runoff were strongly influenced by soil nutrient concentration. Eghball and Gilley (1999) concluded that the application of manure under no–till conditions without incorporation could result in P runoff concentrations that exceed established water quality standards for DP.

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Most feed grains store P as phytate (phytic acid). This form of P is largely unavailable to monogastric animals such as swine. The present practice is to offset low P bioavailability in grain by supplementing feeds with inorganic P. This supplementation represents an added cost, results in poor P use efficiency, and produces manure containing relatively large amounts of P. Land application of manure–borne nutrients at rates that exceed the amount of nutrient removed with the harvested crop creates the potential for environmental contamination.

Phytase is a commercially available enzyme that breaks down the phytate molecule making the P available. To improve P use efficiency in swine, phytase may be added as a feed supplement. Another approach for improving the bioavailability of feed grain P is the use of low–phytate corn. Low–phytate corn stores a majority of its P as inorganic P rather than phytate (Ertl et al., 1998). Increasing the naturally available P results in decreased feed costs by eliminating the need for supplements (phytase or P). The objective of this study was to compare the concentrations and total amounts of P and N transported in runoff from three soils following the application of manure produced by swine fed three selected corn diets.

Materials and Methods

Soil Characteristics

This study was conducted on three soils that had been previously identified as benchmark soils because of their regional or national importance (Laflen et al., 1991). The soils were selected primarily because of their widely varying textual characteristics. Manure had not been applied previously to the three soils.

Surface residue from the sample collection areas was first removed by raking. Soil samples were then obtained from the top 7.6 cm of the soil profile using a shovel and stored in plastic containers until they were used. At the time of collection, large clods were broken by hand, and the soil was sieved through a screen with 12 mm openings. Soil water contents at the time of collection for the Hersh, Pierre, and Sharpsburg soils were 12%, 18%, and 25%, respectively.

Samples for soil characterization were obtained from each plastic container using a 1.9 cm diameter coring device. Five individual samples were combined for chemical analysis. Particle–size analyses and organic matter content were determined using procedures outlined by Gee and Bauder (1986), and Nelson and Sommers (1982), respectively. Phosphorus and N concentrations, and EC, and pH of the three soils before manure application are given in table 1.

Table 1. P and N concentrations and EC and pH of the soils before manure application.

Soil	WSP[a] (mg kg^{-1})	BKP[b] (mg kg^{-1})	NO_3–N (mg kg^{-1})	NH_4–N (mg kg^{-1})	EC[c] (d S m^{-1})	pH[c]
Hersh	4.9	35.0	68.4	0.5	0.5	4.6
Pierre	4.0	5.7	12.2	0.0	0.6	7.5
Sharpsburg	6.7	52.1	54.1	0.2	0.6	6.7

[a] Water–soluble P.
[b] Bray and Kurtz No. 1 extractable P.
[c] EC (electrical conductivity) and pH were determined in 1:1 soil/water ratio.

The Hersh soil (coarse–loamy, mixed, mesic Typic Ustorthent) was obtained from a site located near Grand Island, Nebr. that had been cropped to corn (*Zea mays* L.) the previous season. The Hersh series consists of deep, well–drained, moderately rapidly permeable soils that formed in mixed sandy and loamy aeolian materials on uplands and stream terraces. This sandy loam soil contained 57% sand, 31% silt, and 12% clay, and had an organic matter content of 1.60%.

A site near Cottonwood, South Dakota, that had been cropped to winter wheat (*Triticum aestivum* L.) the previous season was the source of the Pierre soil (fine, smectitic, mesic Aridic Haplustert). The Pierre series consists of well–drained soils on uplands that formed from clay shale. The sand, silt, and clay contents of this silty clay soil were 4%, 46%, and 50%, respectively, and organic matter content was 2.11%.

The Sharpsburg soil (fine, smectitic, mesic Typic Argiurdolls) was obtained from a site near Lincoln, Nebraska, that had been cropped to soybean (*Glycine max* (L.) Merr) the previous season. The Sharpsburg soil formed in loess under prairie vegetation. This silty loam soil contained 7% sand, 65% silt and 28% clay, and had an organic matter content of 3.10%.

Manure Characteristics

Supplies of grain for the traditional corn diet (TCD) and the low phytate corn diet (LPC) were produced under irrigation near Shelton, Nebr. Each diet was fed to feeder pigs located in seven pens. Both urine and feces produced by the 15–20 feeder pigs in each pen were collected three times each week from trays located below the pigs.

Feeder pigs in a separate production facility were given a traditional corn diet supplemented with phytase at a rate of 300,000 FTU Mg^{-1} of feed (PHY). Urine and feces from the swine fed the PHY diet were stored in a pit below the slatted floor of the swine production facility. Water used to remove and clean the manure from the slatted floor was also discharged into the pit. As a result, the PHY manure samples were diluted and contained much less dry matter than the LPC and TCD treatments (table 2).

Manure from each treatment was stored in a freezer prior to application. Manure application rates are often based on estimated nutrient requirements for a particular crop yield. The nutrient content of the manure is measured, and by estimating the percentage of the nutrient that is available for plant consumptive use, the appropriate application rate can be calculated. The amount of Total N and Total P contained in manure from the PHY source was 56% and 14%, respectively, of the quantity present in the TCD. The 7.6 cm soil profile on which the liquid swine manure was applied had a limited infiltration and storage capacity. Rather than

Table 2. Application rates of N and P (dry weight basis) and dry matter of swine manure.

Manure source[a]	NO_3–N (g ha^{-1})	NH_4–N (kg ha^{-1})	Total N (kg ha^{-1})	Total P (kg ha^{-1})	Dry matter (g ha^{-1})
LPC	5	141	145	49	42.7
PHY	5	103	104	10	15.0
TCD	14	179	185	70	48.9

[a] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.

attempt to apply different amounts of liquid manure from the varying manure sources, an application rate of 48 Mg ha^{-1} was used for each of the three swine diets. Application rates of N and P from the three manure sources are shown in table 2.

Experimental Design

This study was conducted as a completely randomized factorial design with two replications. A complete factorial arrangement of the Hersh, Pierre, and Sharpsburg soils and the following five treatments was used:(1) untreated check; (2) inorganic commercial fertilizer applied at rates of 151 kg N ha^{-1} and 25.8 kg P ha^{-1} as ammonium nitrate 34–0–0 (N–P–K) and 18–20–0 (N–P–K), respectively; and manure obtained from swine fed a diet containing (3) LPC; (4) PHY; and (5) TCD.

Analysis of variance (ANOVA) was used to determine differences in runoff and erosion measurements, water quality parameters, and total amounts of dissolved nutrients between soils and manure or fertilizer treatments. Because of non–normality and large variability in the concentrations and total amounts of P and N parameters, values were adjusted using a log transform (parameter +10) (Steel and Torrie, 1980). ANOVA was performed on the transformed data. In these analyses, time of runoff sampling was considered a subsample. A probability level <0.05 was considered significant.

Runoff, Erosion, and Nutrient Measurements

A 1 m × 1 m × 10.2 cm stainless steel soil pan, which was maintained at a 9% slope, was used in this study. The 9% slope was arbitrarily selected to provide optimum interrill sediment transport conditions. A trough extending across the lower end of the pan collected the runoff. Three outlets were located on the floor of the pan to provide subsurface drainage. To facilitate water movement to the outlets, two wire screens (6 and 3 mm mesh) and cotton fabric were placed on the pan floor before filling with soil (Lattanzi et al., 1974).

Soil was placed in the soil pan in four successive layers. The first three layers were compressed by hand with a wooden block to obtain a uniform bulk density. For the Hersh, Sharpsburg, and Pierre soils, bulk density values of 1.5, 1.4, and 1.3 g cm^{-3}, respectively, were used. These bulk density values were obtained from field measurements of the 0 to 7.6 cm soil depth at the time the soil samples were collected. A fourth layer approximately 2 cm thick was applied on the top and leveled without compressing, resulting in a total soil depth of approximately 7.6 cm. The manure was thoroughly mixed with the soil to be used in the fourth layer before it was added to the soil pan. Because of the relatively small quantity of fertilizer that was used, fertilizer was applied to the soil surface on the fertilizer treatments. Following individual tests, all of the soil material was removed, the soil pan was cleaned, and additional soil from another plastic container was placed in the soil pan for subsequent testing.

A rainfall simulator, based on a design by Meyer and Harmon (1979), applied rainfall to the soil pan. An initial 1–h application at an intensity of approximately 64 mm h^{-1} was applied at existing soil water conditions. A second 1–h application (wet run) at the same intensity was conducted approximately 24 h later. The water used in the rainfall simulator had a NO_3–N concentration of 0.4 mg L^{-1}.

Runoff samples were obtained at 5–min intervals until approximately 800 ml were collected. The plastic bottles were weighed, dried, and re–weighed to determine the mass of sediment and water contained in the bottles. Runoff and erosion amounts were computed from the mass of water or sediment, sample collection period, and the contributing area.

The runoff samples contained both manure and sediment. Since the quantity of added manure was small compared to the total amount of soil, the relative quantity of manure solids in the runoff was considered to be minimal (Gilley and Eghball, 1998). Thus, total solids in runoff are reported simply as erosion.

Runoff samples collected 5, 10, 15, 30 and 45 min after initiation of runoff from each pan were centrifuged, filtered, and analyzed for DP (Murphy and Riley, 1962), NO_3–N, and NH_4–N concentrations using a Lachat (Zellweger Analytics, Milwaukee, Wis.) system. Non–centrifuged samples were analyzed for Total P (Johnson and Ulrick, 1959), Total N (Tate, 1994), pH, and EC. Bioavailable P (BAP) in the runoff samples was measured using iron oxide–impregnated paper strips (Sharpley, 1993).

Results and Discussion

Runoff and Erosion Measurements

No significant soil × treatment interactions were indicated by ANOVA of the runoff and erosion measurements. Therefore, Duncan's Multiple Range Test was used to identify significant differences in runoff and erosion values between the soil and manure or fertilizer treatments. During the initial rainfall simulation run, significant differences in runoff were measured between the three soils (table 3). The Pierre soil, with a relatively large clay content and water storage capacity, had the least amount of runoff. The greatest amount of runoff occurred from the Hersh soil because of its relatively large sand content and small water storage capacity. Runoff amounts during the wet run were similar between the three soils. Substantial crusting or surface sealing was not apparent on any of the three soils. Significant differences in erosion were found between the soils for both simulation runs. Thus, interrill erodibility values for the three soils used in this study appear to be substantially different.

During the initial run, runoff and erosion values for the manure treatments were significantly greater than the check treatment. Swine manure, which was mostly liquid, was mixed with the last soil increment before the initial rainfall simulation tests. As a result, soil water content near the soil surface at the time of the rainfall simulation tests was greater in the manure treatments. Thus, runoff amounts during the initial run would be expected to have been larger on the plots where manure was applied. Runoff amounts for the manure treatments were also similar during the initial and wet runs because of the relatively large initial soil water contents on the manure plots.

An incubation period following manure application was not used in this investigation. In some previous studies, the application of manure followed by an incubation period has resulted in reduced rates of erosion (Chandra and De, 1982; Westerman et al., 1983). The long–term application of manure to some soils may enhance the quantity and quality

Table 3. Runoff and erosion as affected by soil type and the application of manure or fertilizer[a].

Experimental variable	Initial run Runoff (mm)	Initial run Erosion (Mg ha^{-1})	Wet run Runoff (mm)	Wet run Erosion (Mg ha^{-1})
Soil[b]				
Hersh	34 a	15.7 a	35 a	14.5 a
Pierre	22 c	4.8 c	30 b	5.1 c
Sharpsburg	29 b	9.8 b	32 ab	9.2 b
Manure or fertilizer treatment[c]				
Check	20 c	5.5 d	29 b	8.2 bc
Fertilizer	23 c	5.9 cd	30 b	6.8 c
LPC	30 b	11.8 b	33 b	11.4 ab
PHY	40 a	18.1 a	39 a	12.9 a
TCD	30 b	9.2 bc	30 b	8.5 bc

[a] Runoff and erosion measurements on 1 m^2 plots are reported for rainfall simulation runs of 60 min duration at an average intensity of 64 mm h–1.
[b] For a given soil, treatment, and simulation run, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[c] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.

of soil aggregates. At present, the incubation period required to induce changes in erodibility is not well defined.

Phosphorus and Nitrogen Concentrations

For both the initial and wet rainfall simulation runs, significant soil × treatment interactions were indicated by ANOVA of the water quality parameters. As a result, Duncan's Multiple Range Test was used to identify significant differences in water quality parameters caused by manure or fertilizer additions to individual soils (tables 4 and 5). In general, runoff from the Pierre soil contained the smallest concentration of nutrients. The Pierre soil, with its relatively large clay content and surface area, may have been able to adsorb a greater quantity of nutrients.

For the initial rainfall simulation run (table 4), runoff concentrations of DP, BAP, and Total P were generally significantly greater for the fertilizer treatment than any of the manure treatments. During the wet run (table 5), concentrations of DP, BAP, and NO_3–N on the fertilizer treatments were reduced substantially when compared to the initial run, but were still generally greater than the manure treatments. In contrast, concentrations of Total P and Total N on the fertilizer and selected manure treatments were similar. Much of the inorganic fertilizer that had been surface applied in a solid form appears to have been dissolved, transported from the plots, or had infiltrated during the two rainfall simulation runs.

On the Hersh and Pierre soils, concentrations of DP, BAP, Total P, NH_4–N, and Total N on the LPC treatments were equal to or larger than the TCD treatments (tables 4 and 5) during both rainfall simulation events. Concentrations of Total P and Total N on the Sharpsburg soil were similar on the LPC and TCD treatments for the two simulation runs. Thus, changing swine diet to produce the manure used on the LPC treatments did not generally result in a decrease in nutrient concentrations in runoff.

For both rainfall simulation runs, runoff concentrations of DP, BAP, Total P, NH_4–N, and Total N on the PHY treatments were generally less than on the TCD treatment on the Pierre and Sharpsburg soils (tables 4 and 5). On the Hersh soil, nutrient concentrations in runoff were similar on the PHY and TCD treatments. Thus, the concentrations of nutrients transported in runoff were affected by soil type. Water used for the rainfall simulation tests had an average NO_3–N concentration of 0.4 mg L^{-1}. For selected treatments, NO_3–N concentrations in runoff were less than 0.4 mg L^{-1} during both rainfall simulation events (tables 4 and 5).

A flow–weighted annual DP concentration of 1 mg L^{-1}, similar to the upper limit imposed on sewage treatment plants, has been proposed for agricultural runoff in some parts of the country (USEPA, 1986). The 1 mg L^{-1} limit was exceeded in runoff samples from the fertilizer treatments on each of the soils during both simulation events (tables 4 and 5). The DP concentration of runoff was generally less than the critical limit on the PHY treatments.

An NH_4–N concentration greater than 2.5 mg L^{-1} has been identified as potentially harmful to fish (USEPA, 1973).

Table 4. Runoff water quality parameters as affected by soil and the application of manure or fertilizer during the initial rainfall simulation run[a].

Soil[b]	Treatment[c]	DP (mg L^{-1})	BAP (mg L^{-1})	Total P (mg L^{-1})	NO_3–N [d] (mg L^{-1})	NH_4–N (mg L^{-1})	Total N (mg L^{-1})	EC (d S m^{-1})	pH
Hersh	Check	0.23 c	0.92 c	10.2 d	0.1 b	0.1 d	42.6 b	0.37 a	7.2 a
	Fertilizer	36.15 a	46.83 a	43.8 a	6.8 a	18.7 c	155.6 a	1.29 a	6.9 c
	LPC	6.23 b	12.59 b	30.9 b	2.4 ab	37.0 ab	121.1 a	1.02 a	7.1 b
	PHY	1.04 c	2.06 c	18.5 c	3.5 ab	26.2 bc	110.1 a	0.74 a	7.1 ab
	TCD	1.97 c	3.81 c	19.9 c	0.1 b	41.9 a	125.6 a	0.99 a	7.0 b
Pierre	Check	0.06 c	0.13 c	3.2 d	0.0 b	0.0 c	53.9 b	0.44 c	8.2 a
	Fertilizer	22.26 a	32.60 a	35.3 a	0.1 b	14.0 b	61.8 b	0.48 c	7.6 b
	LPC	2.93 b	4.35 b	17.0 b	0.1 b	22.2 a	86.2 a	0.87 a	7.4 b
	PHY	0.42 c	0.55 c	9.3 c	0.2 a	13.6 b	57.7 b	0.64 b	7.4 b
	TCD	3.00 b	5.07 b	15.5 b	0.1 b	23.1 a	84.2 a	0.83 a	7.4 b
Sharpsburg	Check	0.23 c	0.60 c	6.9 c	0.1 b	0.0 d	84.6 b	0.44 e	7.6 a
	Fertilizer	35.98 a	45.26 a	55.2 a	4.1 a	17.0 c	77.7 b	0.56 d	7.1 c
	LPC	0.72 c	1.83 c	20.5 b	2.2 a	25.0 b	131.3 a	0.88 b	7.3 b
	PHY	0.52 c	1.32 c	21.8 b	3.0 a	20.6 bc	109.6 ab	0.72 c	7.3 b
	TCD	3.98 b	5.96 b	23.9 b	0.1 b	35.6 a	150.9 a	1.11 a	7.3 b

[a] Arithmetic average for each soil and manure or fertilizer treatment.
[b] For a given soil, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[c] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.
[d] Water used for the rainfall simulator had an average NO_3–N concentration of 0.4 mg L–1.

Table 5. Runoff water quality parameters as affected by soil and the application of manure or fertilizer during the wet rainfall simulation run[a].

Soil[b]	Treatment[c]	DP (mg L^{-1})	BAP (mg L^{-1})	Total P (mg L^{-1})	NO_3–N [d] (mg L^{-1})	NH_4–N (mg L^{-1})	Total N (mg L^{-1})	EC (d S m^{-1})	pH
Hersh	Check	0.22 c	0.84 b	9.1 c	0.3 b	0.0 d	61.9 b	0.39 c	7.2 b
	Fertilizer	1.91 b	3.49 a	11.9 b	2.2 a	7.7 c	90.9 a	0.44 c	7.2 b
	LPC	3.30 a	4.81 a	18.5 a	1.5 a	23.5 a	97.2 a	0.82 a	7.3 ab
	PHY	0.55 c	1.00 b	13.1 b	1.8 a	13.3 b	89.0 a	0.58 b	7.2 ab
	TCD	0.79 c	1.60 b	13.3 b	0.0 b	27.9 a	102.4 a	0.80 a	7.3 a
Pierre	Check	0.05 c	0.11 b	3.8 d	0.0 b	0.0 d	55.6 b	0.43 d	8.3 a
	Fertilizer	2.12 a	3.29 a	8.9 bc	0.6 a	11.9 b	69.1 ab	0.48 cd	8.0 b
	LPC	0.90 b	2.79 a	11.7 a	0.0 b	14.2 a	68.3 ab	0.77 a	7.5 c
	PHY	0.06 c	0.12 b	7.4 c	0.1 b	8.0 c	56.8 b	0.54 c	7.6 c
	TCD	0.79 b	2.66 a	10.3 ab	0.0 b	12.9 ab	81.0 a	0.71 b	7.3 d
Sharpsburg	Check	0.22 c	0.57 c	6.0 b	0.1 c	0.0 c	75.4 bc	0.45 c	7.8 a
	Fertilizer	2.05 a	3.53 a	11.2 a	6.4 a	10.8 b	57.0 c	0.52 b	7.5 b
	LPC	0.30 c	0.69 c	13.3 a	2.5 b	19.2 a	127.4 a	0.81 a	7.3 c
	PHY	0.09 c	0.44 c	12.8 a	1.6 bc	9.1 b	67.0 bc	0.58 b	7.3 c
	TCD	1.10 b	2.00 b	13.7 a	0.0 c	22.3 a	97.3 ab	0.83 a	7.5 b

[a] Arithmetic average for each soil, and manure or fertilizer treatment.
[b] For a given soil, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[c] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.
[d] Water used for the rainfall simulator had an average NO_3–N concentration of 0.4 mg L–1

Table 6. Runoff water quality parameters averaged across soil treatments at selected times following the initiation of runoff during the initial rainfall simulation run on the manure and fertilizer treatments.

Treatment[a][b]	Time (min)	DP (mg L^{-1})	BAP (mg L^{-1})	Total P (mg L^{-1})	NO3–N (mg L^{-1})	NH4–N (mg L^{-1})	Total N (mg L^{-1})	EC (d S m^{-1})	pH
Check	5	0.19 a	0.67 a	7.0 a	0.2 a	0.1 a	70.9 a	0.41 a	7.6 a
	10	0.18 a	0.59 a	6.7 a	0.1 ab	0.0 a	72.5 a	0.42 a	7.6 a
	15	0.18 a	0.53 a	7.0 a	0.0 ab	0.0 a	63.1 a	0.41 a	7.6 a
	30	0.18 a	0.57 a	7.7 a	0.0 b	0.0 a	62.0 a	0.42 a	7.5 a
	45	0.21 a	0.65 a	8.2 a	0.0 b	0.0 a	59.4 a	0.42 a	7.5 a
Fertilizer	5	49.77 a	58.68 a	65.0 a	14.2 a	25.8 a	211.7 a	1.81 a	7.1 a
	10	40.42 ab	50.17 ab	48.8 ab	8.6 a	23.9 a	81.1 a	0.60 a	7.1 a
	15	35.75 ab	46.86 ab	53.6 ab	3 0 a	16.4 a	102.6 a	0.49 a	7.2 a
	30	23.66 bc	33.40 bc	36.9 bc	1.1 a	12.4 a	101.9 a	0.51 a	7.3 a
	45	16.42 c	25.63 c	27.9 c	1.1 a	10.6 a	135.7 a	0.48 a	7.1 a
LPC	5	4.54 a	8.85 a	26.5 a	2.7 a	37.2 a	149.4 a	1.12 a	7.1 a
	10	4.20 a	8.06 a	26.9 a	1.3 a	32.9 a	130.7 a	0.99 ab	7.2 a
	15	3.68 a	7.83 a	24.4 a	1.5 a	29.2 a	107.5 a	0.90 abc	7.3 a
	30	3.37 a	7.21 a	23.8 a	1.5 a	25.6 a	101.7 a	0.82 bc	7.3 a
	45	2.71 a	5.84 a	18.7 a	1.4 a	21.4 a	105.1 a	0.75 c	7.3 a
PHY	5	0.73 a	1.63 a	22.4 a	4.2 a	28.5 a	115.8 a	0.87 a	7.1 b
	10	0.72 a	1.44 a	19.4 a	3.0 a	24.3 ab	100.5 a	0.76 b	7.2 ab
	15	0.69 a	1.32 a	16.5 a	2.2 a	21.1 abc	91.8 a	0.69 bc	7.3 ab
	30	0.60 a	1.14 a	14.9 a	1.5 a	16.1 bc	85.8 a	0.61 cd	7.3 a
	45	0.57 a	1.13 a	12.7 a	1.2 a	13.7 c	82.1 a	0.57 d	7.4 a
TCD	5	3.56 a	6.32 a	25.4 a	0.1 a	47.6 a	157.8 a	1.21 a	7.2 a
	10	3.34 a	5.63 a	22.4 a	0.1 a	40.3 ab	134.0 ab	1.08 ab	7.2 a
	15	3.20 a	5.11 a	20.5 a	0.0 a	35.2 ab	121.5 ab	0.99 bc	7.3 a
	30	2.71 a	4.48 a	17.5 a	0.0 a	25.9 b	102.5 b	0.84 cd	7.3 a
	45	2.42 a	4.13 a	16.8 a	0.1 a	25.1 b	99.9 b	0.77 d	7.3 a

[a] For a given manure or fertilizer treatment, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[b] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.

During both the initial and wet runs, NH_4–N concentrations for each of the treatments except the check were substantially larger than 2.5 mg L^{-1}.

Temporal Changes in Nutrient Concentrations

Concentrations of DP, BAP, and Total P in runoff from the fertilizer treatments averaged across soil treatments at selected times following the initiation of runoff significantly decreased during both rainfall simulation events (tables 6 and 7). As the fertilizer was dissolved and transported from the plot area, its concentration in runoff would be expected to decrease. In general, concentrations of DP, BAP, Total P, NO_3–N, NH_4–N, and Total N on the manure treatments did

Table 7. Runoff water quality parameters averaged across soil treatments at selected times following the initiation of runoff during the wet rainfall simulation run on the manure and fertilizer treatments.

Treatment[a][b]	Time (min)	DP ($mg\ L^{-1}$)	BAP ($mg\ L^{-1}$)	Total P ($mg\ L^{-1}$)	NO3–N ($mg\ L^{-1}$)	NH4–N ($mg\ L^{-1}$)	Total N ($mg\ L^{-1}$)	EC ($d\ S\ m^{-1}$)	pH ($d\ S\ m^{-1}$)
Check	5	0.17 a	0.53 a	6.4 a	0.3 a	0.0 a	63.8 a	0.42 a	7.8 a
	10	0.17 a	0.50 a	6.8 a	0.1 ab	0.0 a	67.4 a	0.42 a	7.7 a
	15	0.16 a	0.51 a	6.2 a	0.1 ab	0.0 a	58.5 a	0.43 a	7.8 a
	30	0.16 a	0.50 a	6.1 a	0.0 b	0.0 a	72.7 a	0.42 a	7.8 a
	45	0.16 a	0.48 a	6.3 a	0.0 b	0.0 a	71.7 a	0.42 a	7.8 a
Fertilizer	5	3.55 a	5.27 a	12.9 a	7.6 a	12.7 a	87.0 a	0.52 a	7.6 a
	10	2.45 b	4.06 b	11.3 ab	4.5 a	10.8 ab	76.5 a	0.49 a	7.6 a
	15	1.91 c	3.30 c	10.5 b	3.2 a	10.1 ab	80.5 a	0.48 a	7.6 a
	30	1.32 d	2.53 d	9.4 b	1.6 a	9.1 b	76.2 a	0.46 a	7.6 a
	45	1.09 d	2.26 d	9.6 b	1.0 a	8.6 b	75.2 a	0.45 a	7.6 a
LPC	5	1.47 a	2.58 a	13.5 a	1.9 a	23.4 a	96.6 a	0.93 a	7.3 a
	10	1.58 a	2.83 a	15.2 a	1.5 a	21.3 a	97.4 a	0.84 ab	7.3 a
	15	1.58 a	3.12 a	15.8 a	1.4 a	20.1 a	98.5 a	0.79 ab	7.3 a
	30	1.69 a	3.26 a	16.0 a	1.0 a	17.2 a	93.8 a	0.73 b	7.4 a
	45	1.74 a	3.51 a	16.4 a	1.1 a	16.7 a	93.3 a	0.71 b	7.4 a
PHY	5	0.17 a	0.35 a	10.6 a	1.7 a	11.6 a	73.2 a	0.61 a	7.2 a
	10	0.22 a	0.43 a	11.2 a	1.4 a	10.6 a	68.8 a	0.58 ab	7.4 a
	15	0.24 a	0.50 a	11.3 a	1.2 a	10.0 a	71.6 a	0.57 ab	7.4 a
	30	0.27 a	0.65 a	11.3 a	1.0 a	9.5 a	84.4 a	0.55 b	7.4 a
	45	0.29 a	0.70 a	12.0 a	0.9 a	9.1 a	75.3 a	0.54 b	7.5 a
TCD	5	0.67 a	1.47 a	11.5 a	0.1 a	25.3 a	117.1 a	0.89 a	7.3 a
	10	0.78 a	1.84 a	12.7 a	0.0 a	21.5 a	107.0 a	0.81 ab	7.3 a
	15	0.82 a	2.11 a	12.8 a	0.0 a	21.0 a	95.3 a	0.77 bc	7.4 a
	30	1.06 a	2.75 a	13.6 a	0.0 a	19.2 a	91.2 a	0.72 bc	7.4 a
	45	1.19 a	2.85 a	12.4 a	0.0 a	18.8 a	79.1 a	0.69 c	7.4 a

[a] For a given manure or fertilizer treatment, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[b] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.

Table 8. Total amounts of dissolved P (DP), bioavailable P (BAP), total P, and nitrate, ammonium and total N as affected by soil type, and manure or fertilizer treatment during the initial rainfall simulation run[a].

Experimental variable	DP ($kg\ ha^{-1}$)	BAP ($kg\ ha^{-1}$)	Total P ($kg\ ha^{-1}$)	NO_3–N ($kg\ ha^{-1}$)	NH_4–N ($kg\ ha^{-1}$)	Total N ($kg\ ha^{-1}$)
Soil[b]						
Hersh	2.23 a	3.36 a	7.64 a	0.82 a	7.26 a	36.80 a
Pierre	0.82 b	1.24 b	3.21 b	0.02 a	3.41 b	14.00 b
Sharpsburg	1.62 ab	2.17 ab	6.50 a	1.17 a	5.14 b	31.30 a
Manure or fertilizer treatment[c]						
Check	0.04 b	0.13 b	1.56 c	0.02 b	0.01 c	11.65 b
Fertilizer	6.51 a	8.56 a	9.32 a	2.17 a	3.52 b	23.80 a
LPC	1.11 b	2.11 b	6.74 ab	0.50 ab	7.97 a	32.42 a
PHY	0.25 b	0.50 b	6.09 b	0.75 ab	7.16 a	34.29 a
TCD	0.83 b	1.42 b	5.69 b	0.02 b	9.35 a	33.64 a

[a] Nutrient transport measurements were obtained on 1 m2 plots for rainfall simulation runs of a 60 min duration at an average intensity of 64 mm h–1.
[b] For a given soil, and manure or fertilizer treatment, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[c] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.

not vary significantly during either the initial or wet rainfall simulation runs.

Substantial reductions in concentrations of DP, BAP, and Total P were found between the end of the initial run and the beginning of the wet run on both the fertilizer and manure treatments (tables 6 and 7). The extended period between the initial and wet rainfall simulation tests may have provided sufficient time for increased P adsorption onto soil materials. In addition, nutrients in solution at the end of the initial run may have infiltrated into the soil profile before the beginning of the wet rainfall simulation event.

A significant correlation was found between BAP and DP. Data obtained from the check, fertilizer, and manure treatments during both the initial and wet rainfall simulation runs were used to derive the regression equation shown in figure 1. Since information concerning DP is more readily available and easier to obtain than BAP, DP is used as the independent variable in the equation.

Total Phosphorus and Nitrogen Transport

In general, no significant soil × treatment interactions were indicated by ANOVA of the total phosphorus and

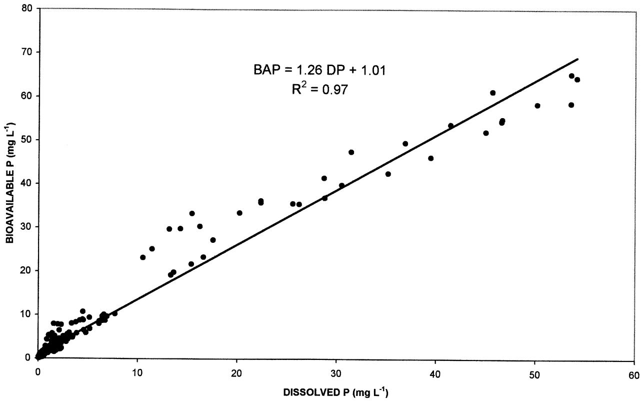

Figure 1. Relationship between bioavailable P (BAP) and dissolved P (DP) for the two rainfall simulation runs.

nitrogen transport data. Therefore, Duncan's Multiple Range Test was used to identify significant differences in total phosphorus and nitrogen transport between the soil and manure or fertilizer treatments. During the initial rainfall simulation run, significant differences in total nutrient transport (except NO_3–N) were found between one or more soils (table 8). Significant differences were also found between soils in total amounts of NO_3–N, NH_4–N, and Total N transported during the wet rainfall simulation event (table 9). In general, the greatest nutrient transport occurred on the Hersh soil and the least on the Pierre soil. Thus, the total amounts of nutrients transported in runoff were significantly affected by soil type. The fact that the loss of nutrients in runoff varies with soil type has been well established (Pote et al., 1996; Sharpley et al., 1996).

For the initial rainfall simulation runs, the transport of DP and BAP was greater on the fertilizer plots than the manure treatments (table 8). However, during the wet rainfall simulation events (table 9), the transport of nutrients from the fertilizer plots was generally similar to the manure plots. In general, the largest total nutrient load occurred on the Hersh soil, and the least was found on the Pierre soil.

The amount of Total P applied on the LPC and PHY treatments was 30% and 86% less, respectively, than the amount applied on the TCD plots (table 2). However, the quantity of Total P transported from the plots during the two rainfall events was similar on the LPC, PHY, and TCD treatments (tables 8 and 9). Thus, changing swine diets to reduce the Total P content of manure did not significantly affect the total transport of DP, BAP, or Total P.

By comparing Total P and Total N contained in runoff during the initial and wet rainfall simulation runs (tables 8 and 9) with the quantity of nutrients that were initially applied in manure (table 2), the percentage of the nutrient that was transported from the plots can be estimated. The residual amount of P or N in the soil before manure application is not considered in the calculation. On the LPC, PHY, and TCD treatments, 24%, 100%, and 14%, respectively, of the Total P that was added was transported from the plots during the two rainfall simulation events. For Total N, 45%, 60%, and 33% of the applied nutrient was transported from the LPC, PHY, and TCD treatments, respectively. Thus, it is apparent that substantial amounts of P and N remained on the LPC and TCD plots following the two rainfall simulation events.

When Total BAP and Total DP were compared, a significant correlation was found. Data obtained from the check, fertilizer, and manure treatments during both the initial and wet rainfall simulation runs were used to derive the regression equation shown in figure 2. It should be noted that the data used to derive figure 2 was obtained from interrill areas. The relationship may be different under concentrated flow conditions.

In this study, nutrient concentrations of runoff were measured soon after the addition of fertilizer or manure. Soil P has been found to have little effect on the P concentration of runoff, when rainfall events occur soon after manure application (Sharpley and Tunney, 2000). The effect of recent manure application on DP transport has been found to decease as the length of time between manure application and surface runoff increases (Sharpley, 1997; Westerman et al., 1983). By reducing the P content of manure that is land applied, the long–term accumulation of P in soil will decrease. Additional testing is required to determine nutrient transport from soils following the long–term application of manure with reduced levels of P.

Results from this study were obtained from interrill areas without crop residue. The presence of crop residue and vegetative materials would be expected to substantially reduce runoff nutrient concentrations, especially of those

Table 9. Total amounts of dissolved P (DP), bioavailable P (BAP), total P, and nitrate, ammonium and total N as affected by soil type, and manure or fertilizer treatment during the wet rainfall simulation run[a].

Experimental variable	DP (kg ha^{-1})	BAP (kg ha^{-1})	Total P (kg ha^{-1})	NO_3–N (kg ha^{-1})	NH_4–N (kg ha^{-1})	Total N (kg ha^{-1})
Soil[b]						
Hersh	0.47 a	0.83 a	4.59 a	0.35 ab	4.75 a	30.98 a
Pierre	0.21 a	0.55 a	2.56 a	0.29 b	2.68 b	19.56 b
Sharpsburg	0.21 a	0.44 a	3.73 a	0.60 a	3.35 b	26.81 ab
Manure or fertilizer treatment[c]						
Check	0.05 a	0.15 a	1.87 b	0.02 b	0.01 c	19.26 a
Fertilizer	0.49 a	0.88 a	3.03 ab	0.75 a	2.82 b	22.07 a
LPC	0.55 a	1.00 a	5.10 a	0.41 ab	5.87 a	32.16 a
PHY	0.11 a	0.26 a	4.45 a	0.45 ab	4.17 ab	28.41 a
TCD	0.29 a	0.74 a	3.78 ab	0.01 b	5.93 a	26.91 a

[a] Nutrient transport measurements were obtained on 1 m^2 plots for rainfall simulation runs of a 60 min duration at an average intensity of 64 mm h–1.
[b] For a given soil, and manure or fertilizer treatment, values with different letters are significantly different at the 0.05 probability level based on Duncan's Multiple Range Test.
[c] LPC = low phytate corn; PHY = phytase added to swine diet; TCD = traditional corn diet.

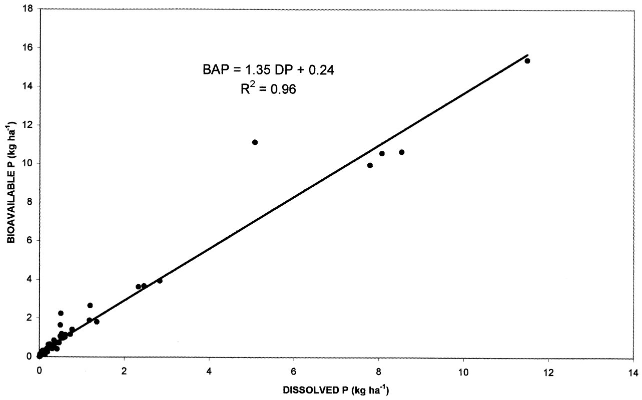

Figure 2. Relationship between the total amount of bioavailable P (BAP) and dissolved P (DP) for the two rainfall simulation runs.

parameters transported principally by sediment. Thus, the runoff nutrient values obtained in this investigation should represent extremes.

CONCLUSIONS

An increase in soil P test level has been shown in the literature to result in greater P transport in runoff. The addition of feed supplements or the use of selected corn hybrids has been found to reduce the P content of manure. By decreasing the amount of P contained in manure, long–term accumulation of P in the soil, and thus the potential for excessive P transport by overland flow, may be reduced. However, soil P test level has been shown to have little effect on the P concentration of runoff when rainfall events occur soon after manure application.

This study was conducted to compare the concentrations and total amounts of P and N in runoff from three soils soon after the addition of swine manure. Manure had not been applied previously to the three soils, and initial soil P test levels were relatively small. Total P in manure from a traditional corn diet (TCD) was applied at a rate of 70 kg ha^{-1}. Adding phytase to the swine diet (PHY) and diluting the resulting manure with wash water from a slatted floor, or using low phytate corn (LPC), resulted in a manure source that contained 14% and 70%, respectively, of the Total P produced from the TCD.

Despite variations in the Total P that was applied, no significant differences were found in the total amounts of DP, BAP, or Total P that were transported from the three manure treatments. On the LPC and TCD plots, only 24% and 14%, respectively, of Total P that was applied was transported from the plots. The quantity of P remaining on the LPC plots greatly exceeded the amount that was transported by overland flow. Thus, changing swine diet to reduce the Total P content of manure on the LPC treatment did not significantly affect total P transport in runoff.

On the Hersh and Pierre soils, concentrations of NH_4–N and Total N on the LPC treatments were equal to or larger than the TCD treatments during both rainfall simulation events. Significant differences were found between soils in the total amounts of NO_3–N, NH_4–N, and Total N transported during the wet rainfall simulation event. For Total N, 45%, 60%, and 33%, respectively, of the applied nutrient was transported from the LPC, PHY, and TCD treatments, respectively.

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