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Runoff nutrient transport as affected by land application method, swine growth stage, and runoff rate

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Abstract. *This study was conducted to measure the effects of slurry application method, swine growth stage, and flow rate on runoff nutrient transport. Swine slurry was obtained from production units containing grower pigs, finisher pigs, or sows and gilts. The swine slurry was applied using broadcast, disk, or injection methods at a rate required to meet annual nitrogen requirements for corn. Three 30 min simulated rainfall events, separated by 24 h intervals, were applied to the experimental plots at an intensity of 70 mm* h^{-1}*. Inflow was applied at the top of each plot in four successive increments after the third rainfall simulation run to simulate greater plot lengths. The dissolved phosphorus (DP) load of 0.20 kg* ha^{-1} *obtained on the broadcast treatment was significantly greater than the 0.11 and 0.08 kg* ha^{-1} *measured on the disk and injected treatments, respectively. The DP runoff load of 0.17 kg* ha^{-1} *measured for the sows and gilts treatment was significantly greater than the 0.11 kg* ha^{-1} *obtained for the finisher treatment. In contrast, the* NH_4*-N load of 0.70 kg* ha^{-1} *obtained on the finisher treatment was significantly greater than the 0.32 kg* ha^{-1} *measured on the grower treatment and the sows and gilts treatment. Runoff rate was an important variable significantly influencing each of the measured water quality parameters. Runoff loads of DP, total phosphorus,* NO_3*-N, and total nitrogen increased from 8.4 to 40.1, from 101 to 659, from 420 to 2470, and from 470 to 2850 g* ha^{-1} min^{-1}*, respectively, as runoff rate increased from 3.2 to 21.2 L* min^{-1}*.*

***Keywords**. Land application, Manure management, Manure runoff, Nitrogen, Nutrients, Phosphorus, Runoff, Soil loss, Swine manure, Water quality.*

Manure can be effectively used for crop production because it contains nutrients (Eghball and Power, 1994). Runoff and erosion have been reduced significantly on sites receiving long-term manure application at appropriate rates (Gilley and Risse, 2000). As manure application rates increased, runoff and soil loss values were found to decrease.

After four years of corn production following the last compost application, phosphorus (P) concentration, EC, and pH of the surface soil were found to be significantly greater on plots receiving compost than on check plots that had received only inorganic fertilizer (Gilley and Eghball, 2002). Since all the organic P contained in compost may not be mineralized and used by the crop in the first two years following compost application, residual P may accumulate within the soil and result in larger soil P values. The $CaCO_3$ that was added to the diet and was contained in the compost caused higher EC measurements and greater pH values. An increase in soil nutrient content may result in greater runoff nutrient concentrations (Gilley et al., 2007a). However, soil nutrient values on cropland may not significantly impact nutrient loss when rainfall occurs soon after manure application, since the contribution to nutrient runoff provided by the manure is substantially larger than that contributed by soil (Eghball et al., 2002).

The effects of application rate and simulated rainfall intensity on water quality following the application of swine slurry to fescue plots were examined by Edwards and Daniel (1993). Both runoff concentrations and event mass losses of all measured slurry constituents except NO_3-N increased approximately linearly with application rate. Runoff concentrations of all measured slurry constituents except NO_3-N decreased with increasing rainfall intensity, but event mass losses were unaffected.

Gilley et al. (2001) compared interrill runoff losses of P and nitrogen from three soils following the application of

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swine slurry obtained from selected diets. Swine manure was obtained from low-phytate corn, phytase added to the diet, and a traditional corn diet, which resulted in different N:P ratios. A manure application rate of 48 Mg ha^{-1} was used for each of the swine diets. Concentrations and total amounts of nutrients transported in runoff were affected by soil type. However, changing the diet to reduce the P content of slurry did not significantly affect the total amount of dissolved P (DP) or total phosphorus (TP) transported in runoff.

The effect of crop residue on nutrient concentrations in runoff from areas where swine slurry was recently applied but not incorporated was examined by Nicolaisen et al. (2007). When swine slurry was applied to plots containing residue materials, nutrient concentrations in runoff were not affected by the amount of crop residue on the soil surface. In addition, no significant differences in runoff nutrient concentrations were found between the residue and no-residue treatments.

The objectives of this study were to: (1) determine the effects of slurry application method and swine growth stage on runoff nutrient loads (mass per unit area) occurring soon after manure application, and (2) compare the effects of slurry application method, swine growth stage, and selected runoff rates on nutrient transport rates (mass per unit area per unit time).

MATERIALS AND METHODS

SLURRY COLLECTION

Swine slurry was collected from the USDA Meat Animal Research Center (MARC) near Clay Center, Nebraska, just prior to field application. All the swine were housed in mechanically ventilated barns and were fed a specific corn and soybean-based diet. A subsample of the swine slurry was collected each week for solids and nutrient analyses, which were performed at a commercial laboratory (table 1). The information on slurry characteristics was used to calculate nutrient application rates (table 2).

Manure from the grower pigs (23 to 68 kg) was pushed through slots in the pen floor and was collected in channels under the pen. Typically, 2000 L of well water was discharged at approximately 1 h intervals through the trough to flush the manure slurry to a common lagoon system. The slurry collection point was accessed through a cover just outside the building at the point where the two channels in the building joined together. The flush system was turned off overnight to allow solids to collect in the trough system. Thus, the resulting slurry was less diluted, and a smaller volume was required to meet crop nutrient requirements. The slurry was collected the following morning at the beginning of the first flush using plastic buckets.

The sows and gilts were housed in the same type of building as the grower pigs. A similar manure handling system was present, and the flush system was turned off overnight to allow solids to build up. The collection point for this building was located 4 m below the ground level. Three separate pipes from different swine housing complexes discharged to the collection point. To isolate and collect slurry from the facility containing the sows and gilts, the flush systems to the other housing complexes were turned off, and the collection well was allowed to drain. Temporary dams were put in place in front of the two inlet pipes coming from the non-target housing complexes and the effluent pipe leading to the common lagoon system. This allowed the water level to build up in the collection well to a sufficient depth to allow the use of a submersible pump. Slurry was obtained at the beginning of the flush cycle.

A pull-plug manure handling system was used in the building containing the finisher pigs (replacement gilts) (68 to 120 kg). The manure was allowed to collect in pits under the slotted pen and was drained once a week by pulling a plug and allowing the system to empty. After draining, the plug was replaced and well water was allowed to refill the pit to approximately a 0.5 m depth. Slurry was collected from this facility by removing a grate and dipping a plastic bucket into the slurry collection pit.

Table 2. Nutrient application rates for slurry obtained from swine at selected growth stages (standard deviations shown in parentheses).

Growth Stage	Slurry Application (Mg ha^{-1})	NH_4-N (kg ha^{-1})	Total Available N[a] (kg ha^{-1})	Total P (kg ha^{-1})
Finisher	230 (51)	183 (16.9)	151 (0)	27 (9.6)
Grower	270 (158)	120 (45.6)	151 (0)	59 (10.9)
Sows and gilts	280 (250)	129 (11.9)	151 (0)	93 (25.5)

[a] Total available N values were calculated by assuming that 70% of the total nitrogen in the slurry would be available the first year following slurry application.

STUDY SITE CHARACTERISTICS

This field study was conducted at the University of Nebraska Rogers Memorial Farm, located 18 km east of Lincoln, Nebraska. The study site had been cropped using a long-term no-till management system with controlled wheel traffic. Soybeans (*Glycine max*) were planted during the 2010 season, and herbicide (glyphosate) was applied as needed to control weed growth. The soil at the site developed in loess under prairie vegetation. The Aksarben silty clay loam (fine, smectitic, mesic Typic Argiudoll) contained 15% sand, 57% silt, and 28% clay (Kettler et al., 2001).

Runoff water quality is influenced by soil characteristics near the surface. As a result, soil samples for study site characterization were obtained from the surface down to 2 cm prior to manure application. Soil samples were obtained from approximately six locations, composited, and then air dried following collection.

Table 1. Characteristics of slurry obtained from swine at selected growth stages (standard deviations shown in parentheses).

Growth Stage	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NH_4-N:TN (ratio)	Total N (mg kg^{-1})	Total P (mg kg^{-1})	N:P (ratio)	Dry Matter (%)	EC (dS m^{-1})	pH
Finisher	0.6 (0.4)	788 (113)	0.850 (0.080)	940 (213)	119 (66)	9.34 (3.87)	0.37 (0.13)	7.82 (1.26)	7.6 (0.3)
Grower	0.9 (0.2)	404 (93)	0.555 (0.211)	799 (252)	219 (108)	3.97 (0.90)	0.84 (0.43)	4.26 (0.70)	6.8 (0.5)
Sows and gilts	0.7 (0.3)	441 (328)	0.597 (0.057)	770 (650)	332 (263)	2.37 (0.63)	0.89 (0.74)	4.36 (2.79)	7.2 (0.3)

Mean measured concentrations of Bray and Kurtz No. 1 P (Bray and Kurtz, 1945), water-soluble P (Murphy and Riley, 1962), NO_3-N, and NH_4-N (measured with a flow injection analyzer using spectrophotometry: Lachat system from Zellweger Analytics, Milwaukee, Wisc.) were 43, 5.2, 8, and 4 mg kg^{-1}, respectively. The study site had a mean slope of 5.8%, electrical conductivity (EC) of 0.38 dS m^{-1}, and pH of 6.8 (Klute, 1986). The organic matter and total carbon content of the soil were 4.7% and 2.62%, respectively (Nelson and Sommers, 1996).

Plot Preparation

Thirty-six 0.75 m × 2 m plots were established, with the 2 m plot dimension parallel to the slope in the direction of overland flow. Experimental treatments included manure application method (broadcast, disk, or injected), swine growth stage (check, grower, finisher, or sow and gilts), and runoff rate (3.2, 9.6, 14.2, or 21.2 L min^{-1}). The manure application method was the main plot treatment, and swine growth stage was the subplot treatment (fig. 1). Each of the main plot and subplot treatments were replicated three times. Field tests were conducted on four plots during the week of 23 May 2011 and on eight plots during each of the next four weeks. Slurry was obtained each week in 20 L plastic buckets and then transported to the study site, where it was applied a few hours following collection.

Manure was applied in amounts required to meet none or the annual N requirement for corn (151 kg N ha^{-1} $year^{-1}$ for an expected yield of 9.4 Mg ha^{-1}). When calculating manure application rates, it was assumed that the N availability from swine slurry was 70% of the total amount of nitrogen measured in the slurry (Gilbertson et al., 1979).

A 5 m tandem finishing disk was used on selected plots to lightly incorporate the applied manure to a depth of approximately 8 cm. Disking (single pass) occurred up and down the slope in the direction of overland flow. This condition provided a greater runoff and soil loss potential than would have occurred if tillage had been conducted along the contour. If disking had occurred across the slope contour, perpendicular to the direction of overland flow, there would have been a greater opportunity for the transport of soil between plots containing manure from different swine growth stages.

A commercially available tanker-mounted or tractor-mounted and hose-fed injector-type applicator would have required a much larger quantity of manure than could have been readily obtained from the individual swine production buildings. Therefore, an injection system requiring a much smaller quantity of slurry was used. Four sweeps spaced 51 cm apart were placed on a tool bar that was mounted on a tractor. The tractor was used to establish four trenches across selected plots in a direction perpendicular to overland flow to a depth of approximately 13 cm. Plot borders were then installed. The slurry contained in the 20 L plastic buckets was slowly poured into a funnel placed at the top of a 4 cm diameter PVC pipe positioned vertically above each trench. The end of the PVC pipe was placed at the bottom of the trench. Finally, a rake was used to cover the top of the trenches after the slurry had been added.

Rainfall Simulation Procedures

Water used in the rainfall simulation tests was obtained from an irrigation well. Nutrient contents reported in this article are the difference between nutrient measurements in runoff and those in the irrigation water. Measured mean concentrations of DP, TP, NO_3-N, NH_4-N, and total nitrogen (TN) in the irrigation water were 0.15, 0.15, 16.7, 0.02, and 16.7 mg L^{-1}, respectively. The irrigation water had a mean EC of 0.74 dS m^{-1} and a pH of 7.6.

Rainfall simulation procedures established by the National Phosphorus Research Project were used 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

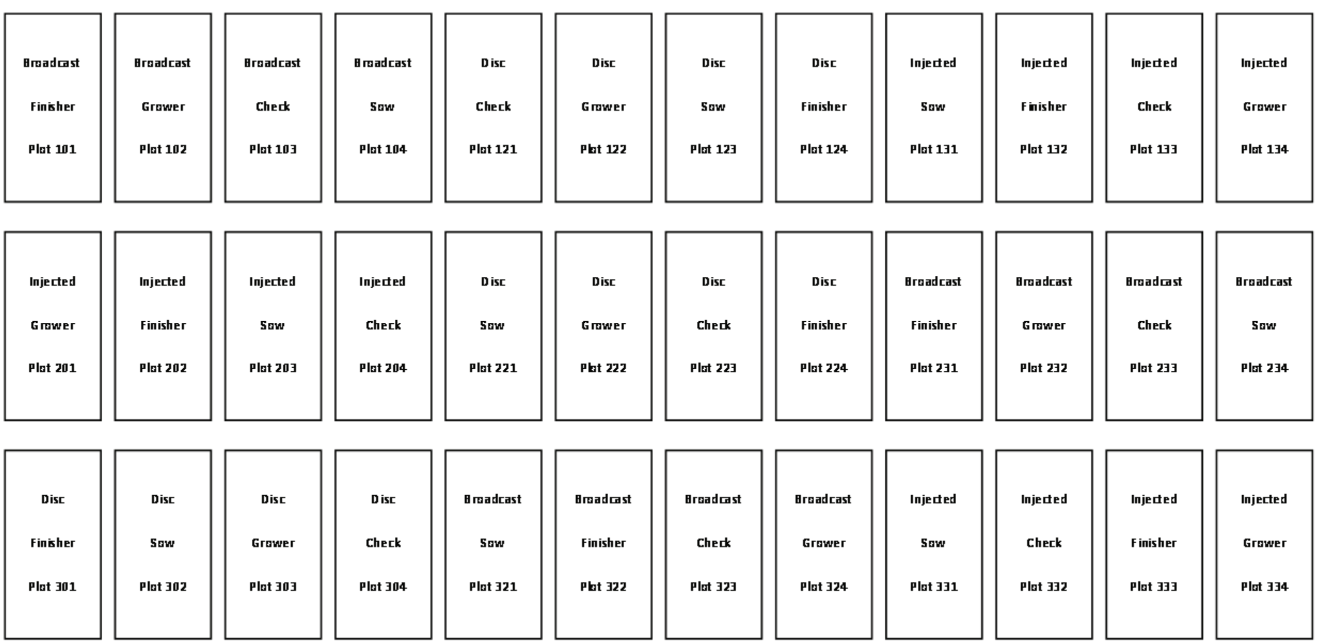

Figure 1. Schematic showing plot layout, slurry application method, and swine growth stage.

were placed along the outer edge of each plot, and one rain gauge was located between the plots. Water was first added to the plots with a hose until runoff began, providing more uniform antecedent soil water conditions. The simulator was then used to apply rainfall for 30 min at an intensity of 70 mm h^{-1}. Two additional rainfall simulation tests were conducted for the same duration and intensity at approximately 24 h intervals.

Plot borders channeled runoff into a sheet metal lip that emptied into a collection trough located across the downslope border of each plot. The trough diverted runoff into plastic buckets. A sump pump was then used to transfer runoff from the plastic buckets into larger plastic storage containers. The storage containers were weighed at the completion of each test to determine the total mass of runoff. Accumulated runoff was agitated to maintain suspension of solids. One runoff sample was collected for water quality analysis, and an additional sample was obtained for sediment analysis.

Centrifuged and filtered runoff samples of a known volume were analyzed for dissolved phosphorus (DP) (Murphy and Riley, 1962), NO_3-N, and NH_4-N using a Lachat system (Zellweger Analytics, Milwaukee, Wisc.). Samples that were not centrifuged were analyzed for TP (Johnson and Ulrich, 1959, pp. 26-78), TN (Tate, 1994), pH, and EC. The samples of a known volume obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment content.

Additional field tests were conducted to identify the effects of varying runoff rate on nutrient transport. Water was added to the test plots to simulate increased runoff rates resulting from larger upslope contributing areas. The addition of inflow to test plots to simulate greater slope lengths is a well established experimental procedure (Monke et al., 1977; Laflen et al., 1991; Misra et al., 1996).

Simulated overland flow was applied at the upslope end of each plot after the third simulation run, while rainfall application continued at a rate of 70 mm h^{-1}. Inflow was added in four successive increments to produce average runoff rates of 3.2, 9.6, 14.2, and 21.2 L min^{-1}. A narrow mat made of green synthetic material often used as outdoor carpet was placed on the soil surface beneath the inflow device to prevent scouring and distribute the flow more uniformly across the plot surface.

A mean overland flow rate of 0.82 L min^{-1} was measured without the addition of simulated overland flow. The largest mean overland flow rate was 21.2 L min^{-1}, or approximately 26 times the value without the addition of inflow. The use of runoff quantities substantially larger than 21.2 L min^{-1} did not seem reasonable for the size of the plots used in this study. Three additional intermediate simulated overland flow quantities were selected to provide overland flow rates useful for comparison.

Runoff was diverted into a flume, where a stage recorder was mounted to measure flow rate. Flow addition for each simulated overland flow increment occurred only after steady runoff conditions for the previous increment was reached and samples for nutrient and sediment analyses had been collected. Steady runoff was determined using the stage recorder and flume. Each simulated overland flow increment was maintained for approximately 8 min.

Statistical Analyses

Analysis of variance was performed using the mixed procedure of SAS (SAS, 2011) to determine the effects of manure application method and swine growth stage on runoff nutrient load and the effects of manure application method, swine growth stage, and simulated overland flow rate on the nutrient transport rate in runoff. If a significant difference was identified, the least significant difference (LSD) test was used to identify differences among experimental treatments. A probability level of $p \leq 0.05$ was considered significant.

Results and Discussion

Phosphorus Load in Runoff

The DP load on the broadcast treatment was 0.20 kg ha^{-1}, which was significantly larger than the 0.11 and 0.08 kg ha^{-1} measured on the disk and injection treatments, respectively (table 3). No significant differences in DP loads were found between the disk and injection treatments. Slurry application method did not significantly affect runoff loads of particulate phosphorus (PP) or TP, which were 0.71 and 0.84 kg ha^{-1}, respectively.

Swine growth stage did not significantly affect runoff loads of PP and TP but did influence DP loads. The DP load of 0.17 kg ha^{-1} measured for the sows and gilts treatment

Table 3. Effects of slurry application method and swine growth stage on water quality parameters averaged over three rainfall simulation runs.

	DP (kg ha^{-1})	PP (kg ha^{-1})	TP (kg ha^{-1})	NO_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	TN (kg ha^{-1})	EC (dS m^{-1})	pH	Runoff (mm)	Erosion (Mg ha^{-1})
Application method[a]										
Broadcast	0.20 a	0.72	0.92	3.57	0.64	4.21	0.77	8.01	19	0.29
Disk	0.11 b	0.99	1.10	4.13	0.31	5.23	0.78	7.99	16	0.31
Injected	0.08 b	0.41	0.49	3.29	0.10	3.39	0.75	8.06	14	0.23
Growth stage[a]										
Check	0.09 b	0.90	0.99	3.77	0.06 b	4.59	0.74 b	8.05	18	0.35
Grower	0.13 ab	0.97	1.10	3.61	0.32 b	4.15	0.76 b	7.99	16	0.27
Finisher	0.11 b	0.50	0.61	3.96	0.70 a	4.66	0.81 a	8.00	16	0.24
Sows and gilts	0.17 a	0.47	0.64	3.33	0.32 b	3.79	0.76 b	8.03	16	0.23
ANOVA (Pr > F)										
Application	0.02	0.34	0.27	0.32	0.09	0.42	0.62	0.74	0.38	0.59
Growth stage	0.05	0.33	0.40	0.72	0.01	0.85	0.01	0.49	0.75	0.32
Application × growth stage	0.28	0.45	0.41	0.09	0.18	0.18	0.77	0.59	0.12	0.44

[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.

was significantly larger than the 0.11 kg ha^{-1} measured for the finisher treatment. The DP load for the grower treatment was 0.13 kg ha^{-1}. The amount of TP contained in the slurry obtained from the sows and gilts, grower, and finisher swine was 93, 59, and 27 kg ha^{-1} (table 2), which followed the measured DP load trend of sows and gilts > grower > finisher treatment.

Gilley et al. (2007b) conducted a field study to measure nutrient transport in runoff as affected by tillage and time following the application of swine slurry at a site on which corn was grown. The rainfall simulation and runoff collection procedures used by Gilley et al. (2007b) were the same as those used in the present investigation. The swine slurry that was applied was obtained from a deep pit located below a slatted floor. Gilley et al. (2007b) applied swine slurry at a rate required to meet a one-year N requirement for corn. For no-till conditions, the mean DP, PP, and TP content of runoff measured four days following application were 0.23, 0.12, and 0.35 kg ha^{-1}, respectively, while mean values of 0.20, 0.72, and 0.92 kg ha^{-1} were obtained in the present investigation for the broadcast treatment. The soil at the study site examined by Gilley et al. (2007b) may have been slightly less erodible, which resulted in smaller PP and TP transport loads than those measured in the present investigation.

Nitrogen Load in Runoff

Slurry application method did not significantly affect mean runoff loads of NO_3-N, NH_4-N, or total nitrogen (TN), which were 3.66, 0.35, and 4.28 kg ha^{-1}, respectively (table 3). In addition, swine growth stage did not significantly affect runoff loads of NO_3-N or TN. The runoff load of 0.70 kg ha^{-1} of NH_4-N measured for the finisher treatment was significantly larger than the 0.32 kg ha^{-1} measured for both the grower treatment and the sows and gilts treatment. The NH_4-N application rate of 183 kg ha^{-1} for the finisher treatment was much larger than the 120 and 129 kg ha^{-1} applied on the grower treatment and the sows and gilts treatment, respectively, (table 2) and is thought to have caused the larger NH_4-N runoff load for the finisher treatment.

The ratio of NH_4-N:TN for the finisher, grower, and sows and gilts treatments was 0.850, 0.555, and 0.597, respectively (table 1). However, the runoff load of NO_3-N was substantially larger than the load of NH_4-N (table 3). Soybeans had been grown on the study site the previous season. Soil analyses indicated that NO_3-N and NH_4-N concentrations in the top 2 cm of the profile when the study was initiated were 8 and 4 mg kg^{-1}, respectively. The NO_3-N load on the check plot where no slurry was applied was not significantly different from the treatments where slurry was added. Therefore, NO_3-N loads in runoff appear to have been influenced by residual soil NO_3-N.

For no-till conditions, Gilley et al. (2007b) found that the mean NO_3-N, NH_4-N, and TN contents of runoff measured four days following swine slurry application were 2.72, 0.47, and 4.58 kg ha^{-1}, respectively. These values were similar to the 3.57, 0.64, and 4.21 kg ha^{-1} measured in the present study for the broadcast condition (table 3).

Measurements of EC, pH, Runoff, and Soil Loss

Slurry application method did not significantly affect electrical conductivity (EC) measurements, which averaged 0.77 dS m^{-1} (table 3). However, the EC measurement of 0.81 dS m^{-1} measured on the finisher treatment was significantly greater than the 0.76 dS m^{-1} obtained on both the grower treatment and the sows and gilts treatment. Neither slurry application method nor swine growth stage significantly affected pH values, which averaged 8.02.

The mean pH of the irrigation water and slurry used in this study was 7.6 and 7.2, respectively. However, the mean pH of runoff was 8.02. Calcium carbonate ($CaCO_3$) was added to the swine diets at each of the growth stages, and it can be assumed that much of the $CaCO_3$ was excreted in manure. After the slurry had been applied to the experimental plots, the liquid portion infiltrated into the soil and much of the solid fraction remained on the soil surface. The $CaCO_3$ contained in the swine manure on the soil surface served to reduce the hydrogen ions contained in runoff and increase pH measurements.

Runoff and erosion, which averaged 16 mm and 0.28 Mg ha^{-1}, respectively, were not significantly affected by slurry application method or swine growth stage. The study site had been cropped for several years using a no-till management system, so minimal erosion occurs at this location. Soil erodibility appeared to have remained small soon after tillage.

The EC and pH of the water used in the rainfall simulation tests conducted by Gilley et al. (2007b) were 0.65 dS m^{-1} and 7.7, while in the present study the EC and pH values were 0.74 dS m^{-1} and 7.6. In the present investigation, soil EC and pH measurements obtained prior to manure application were 0.4 dS m^{-1} and 6.8, which were similar to the EC and pH measurements of 0.5 dS m^{-1} and 6.9 reported by Gilley et al. (2007b). Thus, the EC and pH values for the water applied to the experimental plots and the soil to which the water was added were similar in both investigations. Gilley et al. (2007b) found that for no-till conditions the mean EC and pH of runoff measured four days following swine slurry application were 0.85 dS m^{-1} and 7.31. In the present study, the EC and pH values for the broadcast treatment were 0.77 dS m^{-1} and 8.01. The smaller nutrient content values of the slurry used in the present investigation appeared to have resulted in smaller EC and larger pH values for runoff.

Mean measured runoff and erosion on the no-till swine manure treatments were found by Gilley et al. (2007b) to be 24 mm and 0.39 Mg ha^{-1}, respectively. In the present study, runoff and erosion values for the broadcast treatment were 19 mm and 0.29 Mg ha^{-1}, respectively. The study area used by Gilley et al. (2007b) was planted to corn three days before the rainfall simulation tests were initiated, which may have caused larger runoff and erosion values than those obtained in the present investigation.

Runoff Characteristics as Affected by Overland Flow

Additional flow was introduced at the top of the plots to simulate greater plot lengths, since the upslope contributing area existing under normal field conditions is much larger than that provided by the 2 m long experimental plots. Rainfall intensity and duration are both highly variable. By relating nutrient transport rate to flow rate, the experimental results are applicable to a much larger range of rainfall and runoff conditions.

Capturing and storing all of the runoff that occurred during the experimental tests where simulated overland flow was introduced was not practical. Therefore, nutrient and sediment samples were collected under steady-state runoff conditions, and nutrient load values per unit time are reported for this portion of the study.

Phosphorus Measurements

Slurry application method and swine growth stage did not significantly affect transport rates for DP, PP, or TP (table 4). However, the rates of transport of DP, PP, and TP were each significantly influenced by runoff rate and increased in a linear fashion from 8.4 to 40.1, from 92 to 619, and from 101 to 659 g ha^{-1} min^{-1}, respectively (table 4; fig. 2). It is apparent from figure 2 that the contribution of DP to TP transport rates was relatively small.

Gilley et al. (2008) conducted a field study to measure the effects of overland flow rate on nutrient transport following the application of swine slurry to plots containing varying amounts of corn residue. The plots were either disked or maintained in a no-till condition following slurry application. The rainfall simulation and runoff collection procedures used by Gilley et al. (2008) were similar to those used in the present investigation. The swine slurry used by Gilley et al. (2008) was obtained from a deep pit located below a slatted floor. The slurry was applied at a rate required to meet a one-year N requirement for corn. The mean PP and TP transport rates measured by Gilley et al. (2008) for conditions where inflow was added varied from 50 to 169 and from 92 to 220 g ha^{-1} min^{-1}, respectively. In the present study where inflow was added, transport rates for PP and TP varied from 92 to 619 and from 101 to 659 g ha^{-1} min^{-1}, respectively. The smaller PP and TP transport rates reported by Gilley et al. (2008) are attributed to the reduced soil loss and associated PP transport resulting from the presence of corn residue on the soil surface.

Nitrogen Measurements

The transport rates for NO_3-N and TN of 1420 and 1620 g ha^{-1} min^{-1}, respectively, were not significantly affected by slurry application method or swine growth stage (table 4). However, the NH_4-N transport rate for the broadcast treatment of 33.5 g ha^{-1} min^{-1} was significantly larger than the 10.5 and 8.9 g ha^{-1} min^{-1} measured for the disk and injected treatments, respectively. The NH_4-N transport rate of 36.1 g ha^{-1} min^{-1} obtained for the finisher treatment was significantly larger than the 16.2 and 15.0 g ha^{-1} min^{-1} measured for the grower treatment and the sows and gilts treatment, respectively (table 4). No significant differences in NH_4-N transport rate were found between the grower treatment and the sows and gilts treatment.

Rates of transport of NO_3-N, NH_4-N, and TN were each significantly affected by runoff rate and varied in a linear fashion from 420 to 2470, from 10.7 to 24.4, and from 470 to 2850 g ha^{-1} min^{-1}, respectively (table 4; fig. 3). The rate of transport of NO_3-N under inflow conditions was substantially greater than the NH_4-N transport rate. Gilley et al. (2008) found that the mean NO_3-N, NH_4-N, and TN transport rates for conditions where inflow was added varied from 573 to 2280, from 36 to 47, and from 609 to 2330 g ha^{-1} min^{-1}, respectively, which were similar to values obtained in the present study.

EC, pH, and Soil Loss Measurements

Values for EC, pH, and soil loss were not significantly affected by slurry application method or swine growth stage (table 4). However, runoff rate significantly affected

Table 4. Selected runoff water quality parameters as affected by slurry application method, swine growth stage, and runoff rate.

	DP (g ha^{-1} min^{-1})	PP (g ha^{-1} min^{-1})	TP (g ha^{-1} min^{-1})	NO_3-N (g ha^{-1} min^{-1})	NH_4-N (g ha^{-1} min^{-1})	TN (g ha^{-1} min^{-1})	EC (dS m^{-1})	pH	Soil Loss (kg ha^{-1} min^{-1})
Application method[a]									
Broadcast	30.1	431	461	1530	33.5 a	1770	0.74	7.61	87
Disk	20.9	271	292	1300	10.5 b	1450	0.74	7.60	127
Injected	22.4	331	353	1430	8.9 b	1630	0.74	7.63	160
Growth stage[a]									
Check	19.5	301	321	1250	3.2 b	1400	0.74	7.63	92
Grower	26.0	379	405	1460	16.2 b	1700	0.74	7.59	103
Finisher	24.4	349	373	1480	36.1 a	1670	0.75	7.63	123
Sows and gilts	27.9	347	375	1480	15.0 b	1690	0.74	7.61	180
Runoff rate[a]									
3.2 L min^{-1}	8.4 d	92 d	101 d	420 d	10.7 c	470 d	0.75 a	7.73 a	27.3 d
9.6 L min^{-1}	20.8 c	279 c	300 c	1140 c	16.9 bc	1330 c	0.74 b	7.62 b	94.1 c
14.2 L min^{-1}	28.5 b	386 b	415 b	1640 b	18.5 ab	1820 b	0.74 b	7.54 d	136 b
21.2 L min^{-1}	40.1 a	619 a	659 a	2470 a	24.4 a	2850 a	0.74 b	7.56 c	240 a
ANOVA (Pr > F)									
Application	0.12	0.23	0.22	0.73	0.03	0.64	0.53	0.34	0.31
Growth stage	0.25	0.70	0.68	0.79	0.01	0.71	0.06	0.07	0.25
Runoff rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Application × growth stage	0.73	0.53	0.56	0.50	0.18	0.57	0.11	0.04	0.74
Application × runoff rate	0.99	0.87	0.88	0.16	0.95	0.89	0.55	0.52	0.02
Growth stage × runoff rate	0.26	0.94	0.94	0.49	0.36	0.79	0.13	0.04	0.17
Application × growth stage × runoff rate	0.69	0.66	0.67	0.28	0.95	0.61	0.03	0.11	0.93

[a] Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.

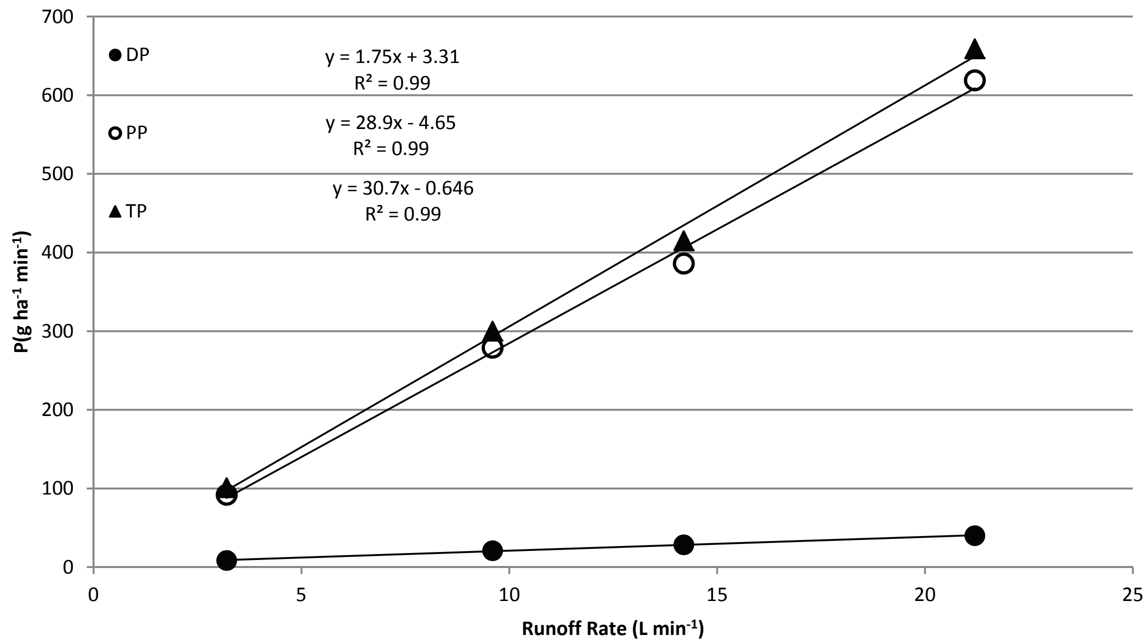

Figure 2. Dissolved phosphorus (DP), particulate phosphorus (PP), and total phosphorus (TP) transport rate as affected by runoff rate.

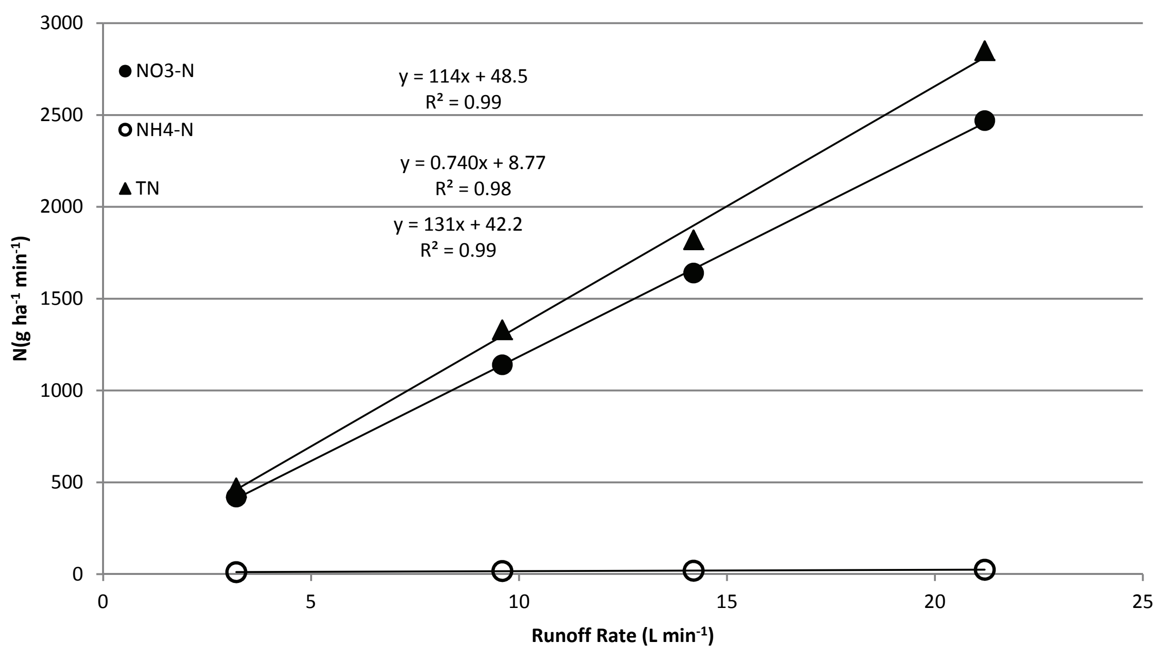

Figure 3. NO_3-N, NH_4-N, and total nitrogen (TN) transport rate as affected by runoff rate.

EC, pH, and soil loss values. Measurements of pH decreased in a linear fashion with runoff rate and varied from 7.73 to 7.54 (table 4). Increased dilution of dissolved constituents in runoff is thought to have been responsible for the reduction in pH values with flow rate.

Soil loss values increased in a linear fashion with runoff rate and varied from 27.3 to 240 kg ha^{-1} min^{-1} (table 4; fig. 4). An increase in soil loss rate with runoff rate is well established. In the absence of concentrated flow, raindrop impact is the principal mechanism providing soil particles for transport by overland flow. Sediment transport mechanisms appeared to have influenced interrill erosion at the study location (Gilley et al., 1985a, 1985b).

CONCLUSIONS

Slurry application method did not significantly affect measured runoff water quality characteristics, except for

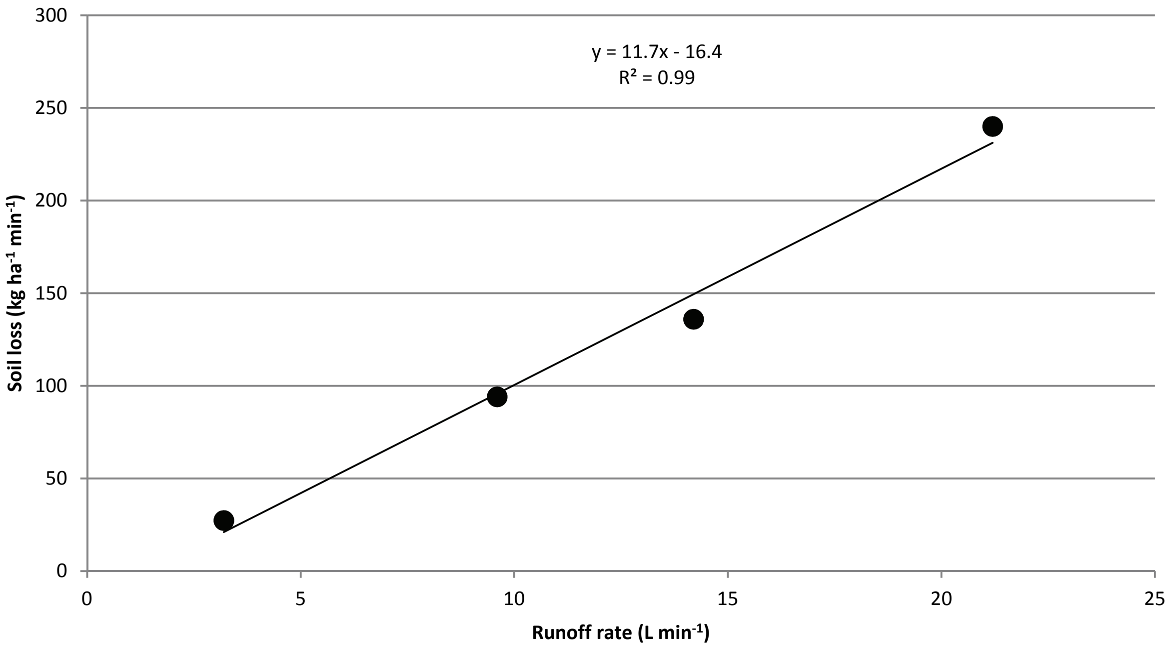

Figure 4. Soil loss rate as affected by runoff rate.

DP load and NH_4-N transport rates. The DP load values of 0.11 and 0.08 kg ha^{-1} measured on the disk and injected treatments were significantly less than the 0.20 kg ha^{-1} obtained on the broadcast treatment. The NH_4-N transport rates of 10.5 and 8.9 g ha^{-1} min^{-1} on the disk and injected treatments were significantly less than the 33.5 g ha^{-1} min^{-1} measured on the broadcast treatment.

The load of DP and NH_4-N in runoff varied significantly for manure obtained from swine at varying growth stages. The TP application rate of 93 kg ha^{-1} for slurry obtained from the sows and gilts production unit was larger than the values for the other swine production facilities, which resulted in a significantly larger DP runoff load of 0.17 kg ha^{-1}. The NH_4-N application rate of 183 kg^{-1} ha^{-1} for slurry from the finisher treatment caused a significantly larger NH_4-N load in runoff of 0.70 kg ha^{-1}.

Each of the measured water quality parameters was significantly influenced by runoff rate. Transport rates for DP, TP, NO_3-N, and TN increased from 8.4 to 40.1, from 101 to 659, from 420 to 2470, and from 470 to 2850 g ha^{-1} min^{-1}, respectively, as runoff rate increased from 3.2 to 21.2 L min^{-1}.

References

Bray, R. N., and T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.* 59(1): 39-45.

Edwards, D. R., and T. C. Daniel. 1993. Runoff quality impacts of swine manure applied to fescue plots. *Trans. ASAE* 36(1): 81-86.

Eghball, B., and J. F. Power. 1994. Beef cattle feedlot manure management. *J. Soil Water Cons.* 49(2): 113-122.

Eghball, B., J. E. Gilley, D. D. Baltensperger, and J. M. Blumenthal. 2002. Long-term manure and fertilizer application effects on phosphorus and nitrogen in runoff. *Trans. ASAE* 45(3): 687-694.

Gilbertson, C. B., F. A. Norstadt, A. C. Mathers, R. F. Holt, L. R. Shuyler, A. P. Barnett, T. M. McCalla, C. A. Onstad, R. A. Young, L. A. Christenson, and D. L. Van Dyne. 1979. Animal waste utilization on cropland and pastureland: A manual for evaluating agronomic and environmental effects. Utilization Research Report No. 6. Washington, D.C.: USDA.

Gilley, J. E., and B. Eghball. 2002. Residual effects of compost and fertilizer applications on nutrients in runoff. *Trans. ASAE* 45(6): 1905-1910.

Gilley, J. E., and L. M. Risse. 2000. Runoff and soil loss as affected by the application of manure. *Trans. ASAE* 43(6): 1583-1588.

Gilley, J. E., D. A. Woolhiser, and D. B. McWhorter. 1985a. Interrill soil erosion: Part I. Development of model equations. *Trans ASAE* 28(1): 147-153, 159.

Gilley, J. E., D. A. Woolhiser, and D. B. McWhorter. 1985b. Interrill soil erosion: Part II. Testing and use of model equations. *Trans ASAE* 28(1): 154-159.

Gilley, J. E., B. Eghball, B. J. Wienhold, and P. S. Miller. 2001. Nutrients in runoff following the application of swine manure to interrill areas. *Trans. ASAE* 44(6): 1651-1659.

Gilley, J. E., B. Eghball, and D. B. Marx. 2007a. Nitrogen and phosphorus concentrations of runoff as affected by moldboard plowing. *Trans. ASABE* 50(5): 1543-1548.

Gilley, J. E., B. Eghball, and D. B. Marx. 2007b. Nutrient concentrations of runoff during the year following manure application. *Trans. ASABE* 50(6): 1987-1999.

Gilley, J. E., W. F. Sabatka, B. Eghball, and D. B. Marx. 2008. Nutrient transport as affected by rate of overland flow. *Trans. ASABE* 51(4): 287-1293.

Humphry, J. B., T. C. Daniel, D. R. Edwards, and A. N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. *Applied Eng. in Agric.* 18(2):199-204.

Johnson, C. M., and A. Ulrich. 1959. Analytical methods for use in plant analysis. Agricultural Experiment Station Bulletin 766. Berkeley, Cal.: University of California.

Kettler, T. A., J. W. Doran, and T. L. Gilbert. 2001. Simplified method for soil particle size determination to accompany soil quality analyses. *SSSA J.* 65(3): 849-852.

Klute, A., ed. 1986. *Methods of Soil Analyses: Part 1. Physical and Mineralogical Methods*. Madison, Wisc.:SSSA.

Laflen, J. M., W. J. Elliot, J. R. Simanton, C. S Holzhey, and K. D.

Kohl. 1991. WEPP soil erodibility experiments for rangeland and cropland soils. *J. Soil Water Cons.* 46(1): 39-44.
Misra, A. K., J. L. Baker, S. K. Mickelson, and H. Shang. 1996. Contributing area and concentration effects on herbicide removal and vegetative buffer strips. *Trans. ASAE* 39(6): 2105-2111.
Monke, E. J., H. J. Marelli, L. D. Meyer, and J. F. Dejong. 1977. Runoff, erosion, and nutrient movement from interrill areas. *Trans. ASAE* 20(1): 58-61.
Murphy, J., and J. P. Riley. 1962. A modified single-solution method for the determination of phosphate in natural waters. *Anal. Chem. Acta.* 27: 31-36.
Nelson, E. W., and L. E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In *Methods of Soil Analysis: Part 3. Chemical Methods*. D. L. Sparks, ed. Madison Wisc.: SSSA.
Nicolaisen, J. E., J. E. Gilley, B. Eghball, and D. B Marx. 2007. Crop residue effects on runoff nutrient concentrations following manure application. *Trans. ASABE* 50(3): 939-944.
SAS. 2011. SAS/STAT User's Guide. Version 9.3. Vol. 1. 4th ed. Cary, NC: SAS Institute, Inc.
Sharpley, A. N., and P. J. A. Kleinman. 2003. Effect of rainfall simulator and plot scale on overland flow and phosphorus transport. *J. Environ. Qual.* 32(6): 2172-2179.
Tate, D. F. 1994. Determination of nitrogen in fertilizer by combustion: Collaborative study. *J. AOAC Intl.* 77(4): 829-839.