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Nutrient Transport as Affected by Rate of Overland Flow

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NUTRIENT TRANSPORT AS AFFECTED BY RATE OF OVERLAND FLOW

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ABSTRACT. *Little information is currently available concerning the effects of varying flow rate on nutrient transport by overland flow. The objective of this study was to measure the effects of overland flow rate on nutrient transport following the application of beef cattle or swine manure to plots containing 0, 2, 4, or 8 Mg ha^{-1} of corn residue. After addition of residue materials to 0.75 m wide by 2.0 m long plots, beef cattle or swine manure was added and the plots were then either disked or maintained in a no-till condition. Three 30 min simulated rainfall events, separated by 24 h intervals, were applied at an intensity of approximately 70 mm h^{-1}. The transport of dissolved phosphorus (DP), particulate P (PP), total phosphorus (TP), NO_3-N, NH_4-N, total nitrogen (TN), and soil loss was measured. Nutrient load from the plots on which manure was applied was not significantly affected by the amount of corn residue on the soil surface. Transport of DP in runoff was greater under no-till than till conditions. Rate of overland flow significantly affected PP and TP load. The transport of NO_3-N and TN was affected by runoff rate but was not significantly influenced by tillage. Both tillage and runoff rate were found to affect the transport of NH_4-N in runoff. Soil loss was significantly influenced by the amount of residue on the soil surface and runoff rate. Tillage condition and runoff rate should be considered when nutrient transport from land application areas is estimated.*

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

Runoff from cropland areas on which manure has been applied may contribute to increased nutrient concentrations in streams and lakes. The concentration of nutrients in runoff may be influenced by nutrient content near the soil surface (Sharpley et al., 1996; Wortmann and Walters, 2006). Greater soil nutrient values have been found to increase runoff nutrient concentrations (Pote et al., 1999; Andraski and Bundy, 2003). However, soil nutrient concentration may not impact nutrient transport when runoff occurs soon after manure application (Eghball et al., 2002a). Nutrient concentrations of runoff may decline during the year following manure application (Gilley et al., 2007a). Moldboard plowing soils with a large nutrient content near the surface has been found to reduce runoff nutrient transport (Gilley et al., 2007b; Wortmann and Walters, 2007).

The incorporation of manure following land application conserves nutrients. Tillage following the addition of beef cattle manure to cropland areas containing sorghum or wheat residue was found to significantly decrease DP concentrations in runoff (Eghball and Gilley, 1999). The amount of crop residue on the soil surface may also be reduced following tillage. However, crop residues may not significantly affect nutrient concentrations in runoff occurring soon after manure application (Nicolaisen et al., 2007).

The National Phosphorus Research Project (NPRP) established procedures for measuring nutrient transport from 2 m long plots (Sharpley and Kleinman, 2003). As slope length increases, runoff rates become greater. Little information is currently available concerning the effects of varying flow rate on nutrient transport by overland flow. The objective of this study was to measure the effects of varying rates of overland flow on nutrient transport following the application of beef cattle or swine manure to plots containing selected amounts of corn residue.

MATERIALS AND METHODS

STUDY SITE CHARACTERISTICS

This field study was conducted at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, Nebraska. 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. Herbicide was applied in April and June of 2002 to control weed growth.

The soil at the site developed in loess under prairie vegetation and had a mean slope of 7%. The Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) contained 11% sand, 54% silt, and 35% clay, and 18.5 g kg^{-1}

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Table 1. Soil characteristics before manure application.

Soil Depth (cm)	WSP[a] (mg kg^{-1})	BKP[a] (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	EC[b] (dS m^{-1})	pH
0-5	6.33	80.0	6.98	2.88	0.49	6.85
5-15	1.13	18.3	5.10	2.59	0.25	5.58

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

of organic C in the top 15 cm of the soil profile. The Murphy and Riley (1962) procedure, which involved shaking 2 g of soil for 5 min in 20 mL of deionized water, was used to determine water-soluble phosphorus (WSP) (table 1). As an index of P availability, the Bray-1 P 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 spectrophotometer (Lachat system from Zellweger Analytics, Milwaukee, Wisc.).

Experimental Design

Forty-eight plots were established across the slope using a randomized block design. Experimental treatments included residue application amount, type of manure, tillage condition, and runoff rate. Corn residue was applied to selected plots at rates of 0, 2, 4, or 8 Mg ha^{-1}, and each residue rate was replicated three times. Beef cattle manure was added to 24 of the plots, and the other 24 plots received swine manure. A tillage variable was included in the experimental design, resulting in 24 till plots and 24 non-till plots. In addition to a no-inflow treatment, four successively larger runoff rates were established to simulate greater slope lengths. The simulation of greater slope length by increasing flow rate has been employed in other studies (Gilley et al., 1990; Gilley and Doran, 1998).

Residue and Manure Characteristics

Corn residue used in this investigation was collected in May 2002 at the Rogers Memorial Farm. The residue materials remained undisturbed following harvest in September 2001 and contained both stalks and leaves at the time of collection. Residue materials were dried in an oven at 60°C and then stored for future use. The drying process allowed the corn residue to be applied to each plot on the basis of uniform dry weight.

Equations have been developed that allow surface cover to be estimated from residue mass. A corn residue mass of 2, 4, or 8 Mg ha^{-1} provides an approximate surface cover of 20%, 37%, and 60%, respectively (Gilley et al., 1986b). Decomposition, residue weathering, and tillage cause residue cover to decrease. The residue rates used in this study (which include a no-residue condition) are representative of a broad range of tillage and management conditions found on cropland areas.

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. Manure characteristics and application rates of N and P are given in table 2.

Plot Establishment

Existing vegetative materials, which consisted primarily of soybean residue, were first removed from the plots by raking. The desired amount of corn residue was applied, and beef cattle or swine manure were then added at rates of 54.1 and 37.1 Mg ha^{-1}, respectively. It was anticipated that beef cattle or swine manure would be applied at the approximate rates required to meet annual corn N requirements. Application rates were determined assuming 40% N availability for beef cattle manure (Eghball and Power, 1999) and 70% N availability for swine manure (Gilbertson et al., 1979). Due to a calculation error, cattle manure was applied at a rate larger than necessary (table 2).

Soil may be transported from its original location during the disking operation. Therefore, manure was added on the tillage treatments to an area larger than the final plot dimensions to provide more uniform application over the plot area. Disking occurred up and down slope in the direction of overland flow. This condition provided a greater runoff and soil loss potential than would have occurred if tillage had occurred along the contour. The tilled plots were covered with tarps after disking to prevent the input of natural rainfall.

Rainfall Simulation Procedures

Water used in the rainfall simulation tests was obtained from an irrigation well. Measured concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were: 0.22, 0.22, 17.3, 0.05, and 17.3 mg L^{-1}, respectively. The irrigation water had an EC value of 0.54 dS m^{-1} and a pH of 7.55.

Field rainfall simulation tests were conducted from 13 June to 30 July 2002 using a portable rainfall simulator based on the design by Humphry et al. (2002). The simulator applied rainfall at an intensity of approximately 70 mm h^{-1} to a pair of 0.75 m wide by 2 m long plots. Procedures established by the National Phosphorus Research Project (NPRP) (Sharpley and Kleinman, 2003) were used during the initial 30 min of the study. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the plots.

Burlap material was placed on the plots to reduce surface disturbance during the pre-wetting process. To provide more uniform antecedent soil water conditions among treatments,

Table 2. Manure characteristics and application rates of nitrogen and phosphorus.

Manure Type	Concentrations (g kg^{-1})[a]				Water Content (g kg^{-1})	EC[b] (dS m^{-1})	pH	Applied (kg ha^{-1})	
	NO_3N[a]	NH_4-N	TN	TP				TN	TP
Cattle	0.18	0.41	9.27	5.05	221	14.8	7.8	501	273
Swine	0.0001	4.07	5.82	1.01	956	25.0	6.8	216	37

[a] Nutrient concentrations of the beef cattle and swine manure were determined on 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.

water was first added to the plots with a hose until runoff began. The quantity of water required to initiate runoff varied among individual plots depending upon existing soil water conditions.

Plot borders channeled runoff into a sheet metal lip that emptied into a collection trough that extended across the bottom of each plot. The trough diverted runoff into aluminum washtubs during the first 30 min of the study due to the relatively small flow rates occurring before the addition of inflow. Mean flow rate during the initial simulation period was 1.05 kg min^{-1}. The washtubs were weighed at the completion of the tests to determine total runoff volume. Accumulated runoff was then agitated to maintain suspension of solids. A runoff sample was collected for water quality analysis, and an additional sample was obtained for sediment analysis.

After the first 30 min of the simulation run, runoff was diverted into a flume on which a stage recorder was mounted to measure discharge rate. Inflow was then added at the top of each plot in four successive increments to produce average runoff rates of 3.11, 7.21, 10.9, and 15.9 kg min^{-1}. Thus, simulated plot lengths were approximately 6, 14, 21, and 30 m. A narrow mat was placed on the soil surface beneath the inflow device to prevent scouring and distribute flow more uniformly across the plot. Flow addition for each inflow increment occurred only after steady-state runoff conditions for the previous inflow increment had become established and samples for nutrient and sediment analyses had been collected. Steady-state runoff conditions were determined using the stage recorder and flume. In general, each inflow increment was maintained for approximately 8 min.

Centrifuged and filtered runoff samples were analyzed for DP (Murphy and Riley, 1962), 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) and TN (Tate, 1994). The samples obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment content.

Statistical Analyses

The effects of tillage, rate of residue addition, and runoff rate on nutrient load were determined using ANOVA (SAS, 2003). For a given plot, water quality measurements obtained from each of the three rainfall simulation runs were included in the analyses. A probability level <0.05 was considered significant.

Results and Discussion

Beef Cattle Manure Treatments

The tillage × residue rate × runoff rate interaction was not significant for any of the nutrient constituents measured on the plots with beef cattle manure (table 3). However, the tillage × runoff rate interaction was significant for PP, TP, NO_3-N, and TN. Nutrient transport in runoff from the plots on which beef cattle manure was applied was not significantly affected by the amount of residue on the soil surface.

Phosphorus Measurements

The transport of DP in runoff was significantly affected by tillage and runoff rate (table 3). The amount of DP in runoff was significantly greater under no-till than till conditions, averaging 47.9 and 20.8 g ha^{-1} min^{-1}, respectively. No significant difference in DP load was found among the three largest runoff rates. Eghball et al. (2000) also found that DP concentrations in runoff from plots containing corn residue were greater on no-till than till treatments. The use of tillage to incorporate dairy manure on areas used to produce corn has been shown to lower concentrations of DP in runoff (Bundy et al., 2001).

Table 3. Runoff water quality parameters as affected by tillage, residue rate, and runoff rate for beef cattle manure.

Variable		Nutrient Constituent (g ha^{-1} min^{-1})						Soil Loss
		DP	PP	TP	NO_3-N	NH_4-N	TN	(kg ha^{-1} min^{-1})
Tillage	No-till	47.9	75.1	123	1340	27.5	1370	55.2
	Till	20.8	26.6	47.4	1190	104	1290	36.1
	$LSD_{0.05}$	19.6	16.1	16.2		63.5		
Residue rate (Mg ha^{-1})	0	29.5	50.0	79.5	1320	64.9	1380	65.1
	2	39.8	57.0	96.8	1280	71.2	1350	43.4
	4	34.3	55.5	89.8	1220	62.0	1280	40.5
	8	33.9	41.6	75.5	1250	65.1	1320	33.6
	$LSD_{0.05}$							12.5
Runoff rate (kg min^{-1})	1.1	19.4	18.8	38.2	347	89.1	436	7.11
	2.9	28.3	31.7	60.0	613	57.4	670	21.4
	7.0	43.9	51.6	95.5	1190	60.8	1250	44.6
	11.5	40.4	69.9	110	1770	61.1	1830	64.7
	16.5	39.7	83.3	123	2400	60.2	2460	90.4
	$LSD_{0.05}$	10.1	10.4	13.7	423	16.9	423	9.4
Analysis of variance (PR > F)								
Tillage		0.03	0.01	0.01	0.38	0.03	0.38	0.08
Residue rate		0.33	0.19	0.22	0.89	0.95	0.89	0.01
Runoff rate		0.01	0.01	0.01	0.01	0.01	0.01	0.01
Tillage × residue rate		0.54	0.65	0.52	0.65	0.18	0.65	0.43
Tillage × runoff rate		0.16	0.01	0.01	0.03	0.08	0.03	0.01
Residue rate × runoff rate		0.45	0.56	0.56	0.54	0.71	0.54	0.01
Tillage × residue rate × runoff rate		0.52	0.64	0.63	0.81	0.96	0.81	0.01

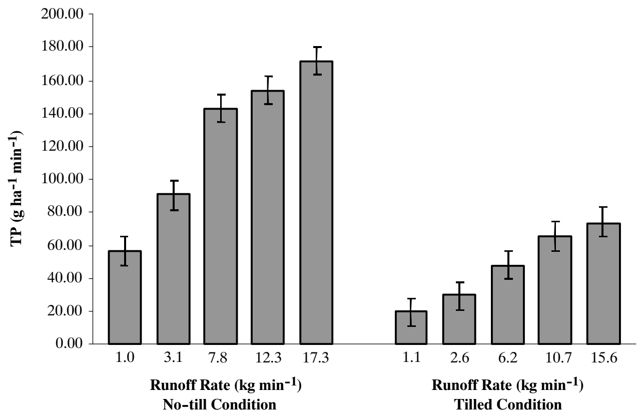

Figure 1. Total phosphorus (TP) load as affected by runoff rate for the no-till and till cattle manure treatments. Vertical bars are standard errors.

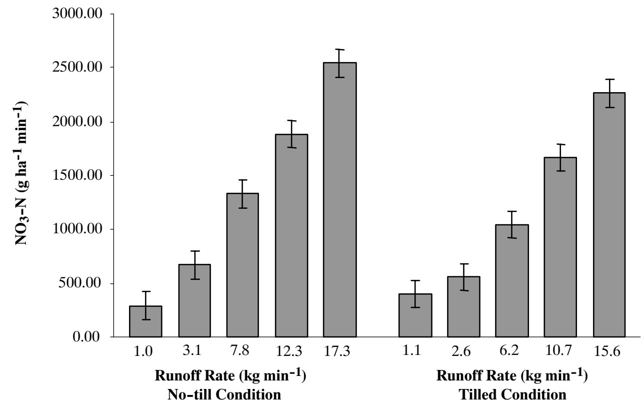

Figure 2. NO_3-N load as affected by runoff rate for the no-till and till cattle manure treatments. Vertical bars are standard errors.

For a given runoff rate, the transport of TP in runoff was significantly greater under no-till than till conditions (fig. 1). Under both no-till and till conditions, the amount of TP in runoff consistently increased as runoff rate became larger. Much of the increase was caused by greater amounts of PP in runoff, especially at higher runoff rates. Experimental results obtained for PP were similar to those identified for TP (table 3). Because of the preferential transport of smaller silt and clay sized soil and organic materials by overland flow, eroded particulate materials are generally enriched with P compared to surface soil (Sharpley et al., 2002).

The amount of TP transported in runoff during the entire testing interval (fig. 1) was compared to the quantity of P that was applied in the beef cattle manure (table 2). Mean P transport under no-till conditions was 2.27%, compared to 0.86% on the tilled plots. Thus, P transport in this study was not limited by the quantity of P contained in beef cattle manure.

Beef cattle manure contains both organic and inorganic forms of P. Approximately 25% of the TP in beef cattle manure is organic P (Eghball et al., 2002b). Soil organic P consists of both labile and stable fractions (Sims and Pierzynski, 2005). Since P in manure is readily attached to soil particles, a more uniform release of inorganic P is expected over time under till conditions. After four years of corn production following the last application of beef cattle compost, the P content of surface soils remained elevated (Gilley and Eghball, 2002).

Nitrogen Measurements

For a given runoff rate, no significant differences in NO_3-N load were found between no-till and till conditions on the treatments containing beef cattle manure (fig. 2). Under both no-till and till conditions, the quantity of NO_3-N in runoff consistently increased as runoff rate became greater. Experimental results obtained for NO_3-N were similar to those determined for TN (table 3).

The amount of NH_4-N carried in runoff was substantially less than NO_3-N transport, especially at the larger runoff rates. The transport of NH_4-N in runoff was significantly affected by tillage and runoff rate. The quantity of NH_4-N transported in runoff was significantly greater under till than no-till conditions, averaging 104 and 27.5 g ha^{-1} min^{-1}, respectively. No significant differences in TN load were found among the four largest runoff rates.

Mineralization of organic nutrients 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).

Swine Manure Treatments

The tillage × residue rate × runoff rate interaction was not significant for any of the nutrient constituents measured from the treatments on which swine manure was applied (table 4). The tillage × residue rate interaction, however, was significant for DP and NH_4-N, while the tillage × runoff rate interaction was significant for DP, NO_3-N, and TN. The amount of corn residue on the soil surface did not significantly affect the transport of nutrient constituents from the plots on which swine manure was applied.

Phosphorus Measurements

The amount of DP in runoff was significantly greater under no-till than till conditions for each runoff rate (fig. 3). For a given tillage condition, no significant differences in DP load were found among the four largest runoff rates. Incorporation of swine manure by disking was found by Tabbara (2003) to significantly reduce flow-weighted concentrations of DP.

The transport of TP in runoff was significantly affected by runoff rate (table 4). As runoff rate increased, TP load became consistently larger. Experimental results obtained for PP were similar to those identified for TP.

The amount of TP transported in runoff during the testing interval was compared to the quantity of P that was applied in the swine manure (table 2). Mean P transport under no-till conditions was 30.1%, compared to 9.8% on the tilled plots. Thus, P transport in this study does not appear to have been restricted by the quantity of P in the swine manure.

The availability of P would be expected to be relatively large, since approximately 91% of the total P in swine manure is in organic form (Sharpley and Moyer, 2000). When simulated rainfall was applied soon after manure application, it was found that changing swine diets to reduce the P content of manure did not significantly affect the total amount of DP transported in runoff (Gilley et al., 2001).

Table 4. Runoff water quality parameters as affected by tillage, residue rate and runoff rate for swine manure.

Variable		Nutrient Constituent ($g\ ha^{-1}\ min^{-1}$) DP	PP	TP	NO_3-N	NH_4-N	TN	Soil Loss ($kg\ ha^{-1}\ min^{-1}$)
Tillage	No-till	79.2	121	200	1340	27.2	1370	47.8
	Till	19.4	59.6	79.0	1210	62.5	1270	51.5
	$LSD_{0.05}$	34.0				18.3		
Residue rate ($Mg\ ha^{-1}$)	0	52.1	102	154	1240	41.0	1280	84.0
	2	50.0	82.0	132	1230	55.3	1290	46.9
	4	49.8	85.2	135	1390	44.6	1430	36.6
	8	45.4	91.6	137	1250	38.4	1290	31.1
	$LSD_{0.05}$							23.4
Runoff rate ($kg\ min^{-1}$)	1.1	54.3	26.8	81.1	702	73.0	775	8.2
	3.3	41.4	50.3	91.7	573	35.7	609	22.8
	7.4	51.9	92.1	144	1210	33.6	1240	46.5
	10.4	47.8	114	162	1630	35.3	1670	67.4
	15.3	51.1	169	220	2280	46.6	2330	103
	$LSD_{0.05}$		41.6	40.8	295	22.6	295	27.9
Analysis of variance (PR > F)								
Tillage		0.02	0.35	0.13	0.09	0.01	0.09	0.83
Residue rate		0.80	0.97	0.96	0.35	0.54	0.35	0.01
Runoff rate		0.07	0.01	0.01	0.01	0.01	0.01	0.01
Tillage × residue rate		0.03	0.13	0.10	0.13	0.03	0.13	0.90
Tillage × runoff rate		0.01	0.25	0.37	0.01	0.36	0.01	0.79
Residue rate × runoff rate		0.24	0.99	0.99	0.49	0.90	0.49	0.03
Tillage × residue rate × runoff rate		0.70	0.17	0.24	0.85	0.62	0.85	0.75

Nitrogen Measurements

For a given runoff rate, no significant differences in NO_3-N load were found between the no-till and till treatments, except for the smallest runoff rate (fig. 4). On the no-till treatment, significant differences in NO_3-N load were found among the four largest runoff rates. The quantity of NO_3-N measured in runoff under till conditions consistently increased as runoff rate became greater. Experimental results obtained for TN were similar to those identified for NO_3-N.

Substantially less NH_4-N than NO_3-N was transported in runoff. Both tillage and runoff rate significantly affected the NH_4-N load in runoff. Significantly larger amounts of NH_4-N were found in runoff under till than no-till conditions, averaging 62.5 and 27.2 g ha^{-1} min^{-1}, respectively. No significant differences in NH_4-N load were found among the four largest runoff rates.

Soil Loss Measurements

Tillage did not significantly affect soil loss measurements on either the beef cattle or swine manure treatments (tables 3 and 4). Soil loss consistently decreased as the amount of residue material became greater on both the beef cattle and swine manure treatments. An increase in residue cover has been shown to decrease soil erosion (Gilley et al., 1986a, 1986b). On both the cattle and swine manure treatments, soil loss became consistently larger as runoff rate increased, which is consistent with results from previous studies (Gilley et al., 1985, 1992). In a previous investigation, Gilley and Eghball (1998) found that a single application of beef cattle manure or compost did not significantly affect runoff or erosion. However, the long-term application of manure has been found to reduce runoff and soil loss (Gilley and Risse, 2000).

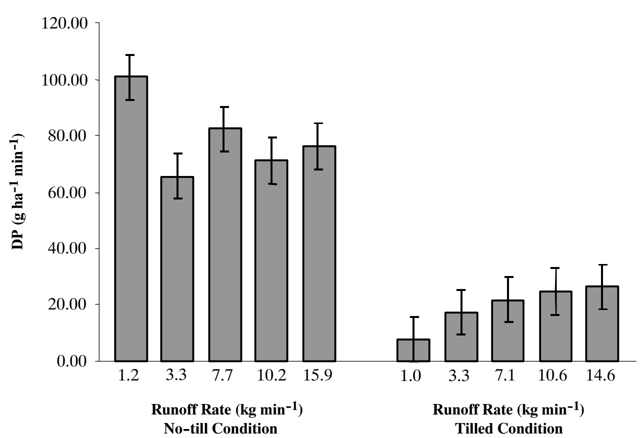

Figure 3. Dissolved phosphorus (DP) load as affected by runoff rate for the no-till and till swine manure treatments. Vertical bars are standard errors.

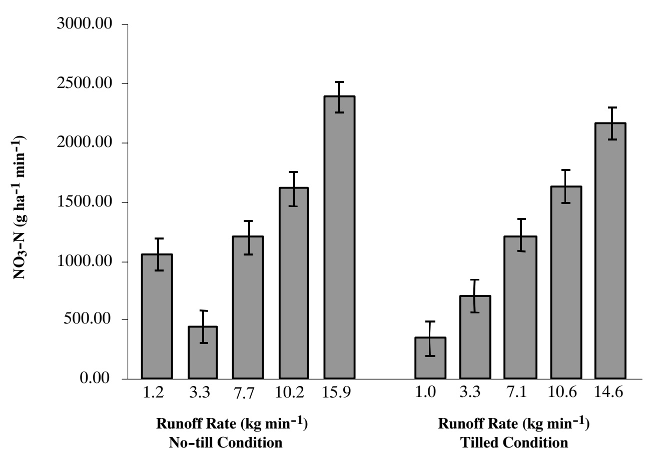

Figure 4. NO_3-N load as affected by runoff rate for the no-till and till swine manure treatments. Vertical bars are standard errors.

Additional Considerations

Rainfall simulation and data collection protocols adopted by the NPRP (Sharpley and Kleinman, 2003) were used in this study. It is recognized that these procedures represent an extreme condition. The occurrence of rainfall for an extended period at an intensity of 70 mm h^{-1} is unlikely to occur under natural rainfall conditions. The opportunity for runoff was enhanced by adding water to the plots prior to the tests to provide more uniform antecedent soil water conditions.

The rainfall simulation tests were conducted soon after manure was applied. Little information is currently available concerning temporal changes in nutrient transport following the addition of manure to cropland areas. Nutrient transport by runoff may decrease with length of time following manure application (Eghball et al., 2002a; Gilley et al., 2007a).

In this study, runoff and erosion were measured soon after a single application of manure. Since manure contains nutrients and organic matter, the application of manure has been effectively used to improve crop production and soil properties. Gilley and Risse (2000) assembled and summarized information quantifying the effects of cattle manure application on runoff and erosion from selected cropland sites in the central and eastern U.S. When manure was applied annually, runoff from natural precipitation events was reduced from 2% to 62% and soil loss decreased from 15% to 65% compared to sites without manure.

Conclusions

Nutrient transport in runoff from plots on which beef cattle manure was applied at a rate in excess of that required to meet annual corn N requirements was not significantly affected by the amount of crop residue on the soil surface. However, tillage and runoff rate affected the transport of DP in runoff. The amount of DP in runoff was significantly greater under no-till than till conditions. For a given runoff rate, the transport of TP in runoff was greater under no-till than till conditions, averaging 47.9 and 20.8 g ha^{-1} min^{-1}, respectively. Under both no-till and till conditions, the amount of TP in runoff consistently increased as runoff rate became larger.

For a given runoff rate on the treatments with beef cattle manure, no significant differences in NO_3-N load were found between no-till and till conditions. The quantity of NO_3-N in runoff consistently increased on both the no-till and till treatments as runoff rate became greater. The transport of NH_4-N in runoff from the beef cattle manure treatments was affected by tillage and runoff rate. The quantity of NH_4-N transported in runoff was significantly greater under till than no-till conditions, averaging 104 and 27.5 g ha^{-1} min^{-1}, respectively.

The amount of crop residue on the soil surface did not affect the transport of nutrient constituents from the plots on which swine manure was applied. For each runoff rate, the quantity of DP transported in runoff was greater under no-till than till conditions. The transport of TP in runoff from the swine manure treatments was significantly affected by runoff rate.

The quantity of NO_3-N measured in runoff from the swine manure treatments under tilled conditions consistently increased as runoff rate became greater. Both tillage and runoff rate significantly affected NH_4-N load in runoff. Larger amounts of NH_4-N were found in runoff under till than no-till conditions, averaging 62.5 and 27.2 g ha^{-1} min^{-1}, respectively.

In this investigation, the transport of nutrients from land application areas was significantly influenced by rate of overland flow. Numerous rainfall simulation studies have been conducted to measure nutrient transport from sites on which manure has been applied. Procedures are needed for using the information obtained from small plot studies to predict nutrient delivery from field-size areas and small watersheds.

Well-established analytical techniques are available for estimating and routing runoff from agricultural areas. It was shown in this study that selected nutrient constituents are significantly influenced by runoff rate. If predictive equations can be derived relating nutrient transport to runoff rate, it may be possible to estimate nutrient delivery from areas with complex topography.

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