1-2012

RUNOFF NUTRIENT LOADS AS AFFECTED BY RESIDUE COVER, MANURE APPLICATION RATE, AND FLOW RATE

Chance Thayer
University of Nebraska-Lincoln, cthayer@live.com

John E. Gilley
Adjunct Professor, Biological Systems Engineering, john.gilley@ars.usda.gov

Lisa M. Durso
USDA-ARS, Lisa.Durso@ars.usda.gov

David B. Marx
University of Nebraska-Lincoln, david.marx@unl.edu

Runoff Nutrient Loads as Affected by Residue Cover, Manure Application Rate, and Flow Rate

C. A. Thayer, J. E. Gilley, L. M. Durso, D. B. Marx

Abstract. *Manure is applied to cropland areas with varying surface cover to meet single-year or multiple-year crop nutrient requirements. The objectives of this field study were to: (1) examine runoff water quality characteristics following land application of manure to sites with and without wheat residue, (2) compare the water quality impacts of land application of manure to meet 0-, 1-, 2-, 4-, and 8-year P-based requirements for corn, and (3) evaluate the effects of varying runoff rates on runoff nutrient loads. Three 30-min simulated rainfall events, separated by 24 h intervals, were applied at an intensity of 70 mm h^{-1} to 0.75 m wide by 2.0 m long plots on which manure has been previously applied and incorporated. Runoff loads of dissolved phosphorus (DP), total phosphorus (TP), NO_3-N, NH_4-N, and total nitrogen (TN) were significantly greater on the plots with residue cover. Manure application rate significantly influenced runoff loads of DP, TP, NO_3-N, NH_4-N, and TN. No significant differences in runoff loads of DP and TP were found between sites where manure was applied to meet a 1-year or 2-year P requirement for corn. However, runoff loads of DP and TP were significantly greater on the sites where manure was applied to meet a 4-year rather than a 2-year P requirement. Each of the measured water quality parameters except electrical conductivity (EC) was significantly influenced by runoff rate. The application of manure to meet multiple-year crop nutrient requirements may increase nutrient loads in runoff.*

Keywords. *Beef cattle, Feedlots, Land application, Manure management, Manure runoff, Nitrogen, Nutrients, Phosphorus, Runoff, Water quality.*

Manure is applied to cropland areas managed using a variety of cropping and tillage conditions that result in varying amounts of crop residue. The incorporation of manure following land application helps to conserve nutrients and reduce odors (Gilley et al., 2007). However, tillage can also decrease the amount of crop residue on the soil surface and increase soil loss potential. Little information is currently available concerning the effects of crop residue on nutrient loads in runoff from sites where manure had been previously applied and then incorporated by tillage.

The long-term application of surplus P in excess of crop nutrient requirements results in the accumulation of surplus soil P. Large residual soil test P has been shown to cause excessive P loads in runoff that may result in water quality degradation (Andraski and Bundy, 2003; Gilley et al., 2008a). Manure is often applied each year to meet crop nutrient requirements. Labor, equipment, and land application costs can be reduced if manure is applied to meet multiple-year crop nutrient requirements (Bremer et al., 2007). However, the water quality impacts of multiple-year manure application have not been well quantified.

Runoff rates on land application areas increase with slope length. As runoff rates increase, there is a potential for increased nutrient losses in runoff. Limited information is currently available concerning the effects of varying runoff rates on nutrient loads following land application of manure.

The objectives of this field study were to: (1) examine runoff water quality characteristics following land application of manure to sites with and without wheat residue, (2) compare the water quality impacts of land application of manure to meet 0-, 1-, 2-, 4-, and 8-year P-based requirements for corn (*Zea mays*), and (3) evaluate the effects of varying runoff rates on runoff nutrient loads.

Materials And Methods

Study Site Characteristics

Field tests were conducted at the University of Nebraska Roger's Memorial Farm located 18 km east of Lincoln, Nebraska, in Lancaster County. The site has been cropped using a grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), and winter wheat (*Triticum aestivum* L. cv. Pastiche) rotation under a no-till management system, and was planted to winter wheat during the 2008-2009 cropping season. Herbicide was applied as needed to control weed growth. The Aksarben (formerly Sharpsburg) silty clay loam at the site (fine, smectitic, mesic Typic Argiudoll) contained 16% sand, 52% silt, 32% clay, 4.6% organic matter, and 2.50% total carbon in the top 8 cm of the soil profile. The soil at the site developed in loess under prairie vegetation and had a mean slope of 6.0%.

Submitted for review in August 2011 as manuscript number SE 9346; approved for publication by the Structures & Environment Division of ASABE in January 2012.

The authors are **Chance A. Thayer, ASABE Member,** Former Graduate Student, Department of Biological Systems Engineering, University of Nebraska, Lincoln, Nebraska; **John E. Gilley, ASABE Member,** Research Agricultural Engineer, and **Lisa M. Durso,** Research Microbiologist, USDA-ARS Agroecosystem Management Research Unit, Lincoln, Nebraska; and **David B. Marx,** Professor, Department of Statistics, University of Nebraska, Lincoln, Nebraska. **Corresponding author:** John E.Gilley, USDA-ARS, Room 251 Chase Hall, University of Nebraska, Lincoln, NE 68583-0934; fax: 402-472-6338; phone: 402-472-2975; e-mail: John.Gilley@ars.usda.gov.

Figure 1. Schematic showing plot layout, wheat residue cover, and manure application rate based on 0-, 1-, 2-, 4-, or 8-year corn phosphorus requirements.

Experimental Design

Thirty plots were established across the slope using a randomized block design (fig. 1). Each of the experimental treatments, which included cover (cover or no cover) and manure application rate (0, 1-, 2-, 4-, or 8-year P-based application for corn), were replicated three times. Rainfall simulation tests were performed separately by block over a five-week period from 29 June to 29 July 2010 with tests conducted on six plots each week.

Plot Preparation

Beef cattle manure was collected from feedlot pens located at the U.S. Meat Animal Research Center near Clay Center, Nebraska. Calves born during the spring of 2009 were placed in the pens in October 2009, and they were fed a corn-based diet. Replicated samples obtained from the feedlot were used to determine the physical and chemical characteristics of the manure. The manure samples were placed in plastic bags and mailed the day of collection by overnight delivery to a commercial laboratory for analyses. The commercial laboratory typically completed the analyses within 24 h after receipt of the samples.

Wheat residue cover was first removed from 15 of the plots by hand raking, and the other 15 plots remained undisturbed. Manure was then added to the experimental plots on 19 May 2010 at rates of 0.0, 5.4, 10.7, 21.4, or 42.8 Mg ha^{-1} to meet 0-, 1-, 2-, 4-, or 8-year P-based application requirements for corn (25.8 kg P ha^{-1} for an expected yield of 9.4 Mg ha^{-1}) (table 1). A total of 27.7 cm of rainfall occurred between the time manure was applied on 19 May 2010 and the rainfall simulation tests began on 29 June 2010.

When calculating manure application rates, it was assumed that N and P availability from the beef cattle manure was 40% and 85%, respectively (Eghball et al., 2002). Sup-

Table 1. Manure and nutrient application rates.

P Application Interval[a] (years)	Manure Application (Mg ha^{-1})	Total Manure N (kg ha^{-1})	Total Fertilizer N (kg ha^{-1})	Total Manure P (kg ha^{-1})
0	0.0	0	0	0
1	5.4	32	119	26
2	10.7	64	87	52
4	21.4	128	23	103
8	42.8	256	0	206

[a] Manure was applied at a rate necessary to meet a 1-, 2-, 4-, or 8-year corn P requirement.

plemental urea ($(NH_2)_2CO$) fertilizer N (39-0-0, N-P-K) was added at rates required to meet annual N crop requirements (151 kg N ha^{-1} for an expected yield of 9.4 Mg ha^{-1}). The 4-year P application rate was less than the 1-year N requirement (table 1). Residual soil nutrient content and the concentration of nutrients in the irrigation water were not considered when calculating the manure and supplemental N fertilizer requirements.

The manure was collected from the feedlot and placed in 19 L plastic buckets. After results from the laboratory analyses were available, the amount of manure required to meet P application requirements was calculated and the desired mass determined. The required mass of manure was then distributed uniformly across the surface using the 19 L buckets. Soil may be transported from its original location as part of the disking operation. Therefore, manure was added to an area slightly larger than the final plot dimensions to provide more uniform application over the experimental area.

A 5 m tandem finishing disk was used to lightly incorporate the applied manure to a depth of approximately 8 cm. It appeared that the applied manure was distributed throughout the tillage zone on both the cover and no-cover treatments. 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 different amounts of manure and/or supplemental N fertilizer.

Wheat residue cover at the time of the rainfall simulation tests on the cover and no-cover treatments was 90% and 5%, respectively. There was a substantial amount of wheat residue on the soil surface prior to tillage, and a large amount of residue remained on the soil surface following the disking operation on the plots where wheat reside was not removed. Soil samples for study site characterization were obtained from the 0 to 2 cm depth on each plot just prior to rainfall simulation testing. Wheat residue that was incorporated by tillage was contained in some of the soil samples collected for laboratory analyses.

Rainfall Simulation Procedures

Rainfall simulation procedures adopted by the National Phosphorus Research Project were employed in this study (Sharpley and Kleinman, 2003). A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall to 0.75 m wide × 2 m long paired plots. The distance between paired plots was approximately 5 m to accommodate the tandem disk used for tillage. The simulator was 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. Some drying on the soil surface occurred between rainfall simulation runs.

Two rain gauges 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 to provide more uniform antecedent soil water conditions. A large rubber mat with numerous holes was placed across the soil surface before the addition of water to allow more uniform distribution and to protect the soil surface from scouring during soil wetting. The amount of water added to each plot was not the same since initial soil water conditions varied among plots during the five-week study period.

Plot borders channeled runoff into a sheet metal lip that emptied into a collection trough located across the bottom of each plot. The trough diverted runoff into plastic buckets. A sump pump was then used to transfer runoff into larger plastic storage containers. The storage containers were weighed at the completion of each run to determine total runoff mass. Because of the relatively large amount of runoff that was collected, measurement of mass was more accurate than measuring runoff volume. The relatively small variations in mass of runoff caused by differences in water temperatures were not considered in the analyses.

Accumulated runoff was agitated immediately before sample collection to maintain suspension of solids. A runoff sample was collected for water quality analysis, and an additional sample was obtained for sediment analysis. The runoff samples were collected within a few minutes following completion of the rainfall simulation tests. It was assumed that the movement of nutrients from solid to liquid phase was minimal during this period.

Centrifuged and filtered runoff samples were placed in a cooler at 2°C and were usually analyzed within 24 h after collection for DP (Murphy and Riley, 1962) and NO_3-N and NH_4-N using a Lachat system (Zellweger Analytics, Milwaukee, Wisc.). Non-centrifuged samples were stored in a cooler at 2°C for a few weeks and then analyzed at a commercial laboratory for TP (Johnson and Ulrich, 1959), TN (Tate, 1994), pH, and EC. The period of time that elapsed between sample collection and analyses was appropriate for the laboratory analyses that were performed. Particulate phosphorus (PP) values were reported as the difference between measurements of TP and DP.

Runoff samples for sediment analyses were collected in 1 L plastic bottles on which tare weights had been previously obtained. The plastic bottles were transported to the laboratory, and total mass was measured. The plastic bottles were dried in an oven at 105°C and then weighed to determine the mass of sediment (total solids) remaining in the plastic bottles. Sediment content was calculated as the mass of material remaining in the bottles after drying divided by the mass of water contained in the bottles before drying (the total measured mass of liquid minus the mass of total solids). When calculating sediment content, it was assumed that the mass of dissolved chemical constituents contained in the runoff was negligible.

Addition of Inflow

Simulated overland flow was applied at the upgradient end of each plot after the first 30 min of the third rainfall simulation run. The addition of inflow to the test plots to simulate greater slope length is a well established experimental procedure (Monke et al., 1977; Laflen et al., 1991). Rainfall continued during the simulated overland flow tests. Inflow was added in four successive increments to produce average runoff rates of 2.15, 8.34, 12.32, and 19.12 L min^{-1} on the plots with residue cover and 2.19, 8.02, 12.11, and 19.96 L min^{-1} on the plots without residue cover.

A mat consisting of a synthetic plastic material typically used for an outdoor carpet was placed on the soil surface beneath the inflow device to prevent scouring and distribute flow more uniformly across the plot surface (fig. 2). Flow addition for each inflow increment usually occurred for

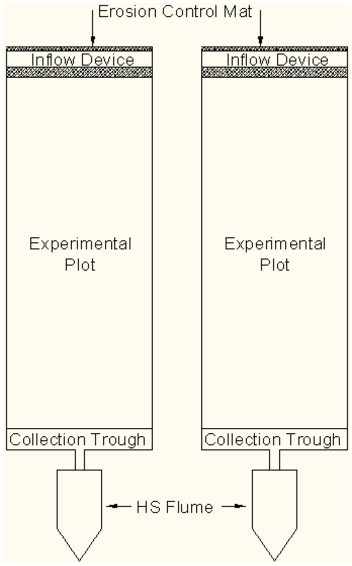

Figure 2. Schematic showing a pair of experimental plots, inflow devices, collection troughs, and HS flumes.

approximately 8 min. This was the period of time typically required for steady-state flow conditions to become established and samples for nutrient and sediment analyses to be collected.

A mean overland flow rate of 1.02 L min^{-1} was measured without the addition of simulated overland flow. The largest mean overland flow rate was 19.54 L min^{-1}, or approximately 19 times the value without the addition of inflow. The use of runoff quantities larger than 20 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-state runoff conditions for the previous increment had been reached and samples for nutrient and sediment analyses had been collected. Steady-state runoff conditions were determined using the stage recorder and flume. Each simulated overland flow increment was maintained for approximately 8 min.

Statistical Analyses

The effects of varying residue cover, manure application rate, and flow rate on runoff nutrient loads 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 and were treated as repeated measures. By using ANOVA, it was possible to test for significant differences among experimental variables. If a significant difference was identified, the least significant difference test (LSD) was used to identify differences among experimental treatments. A probability level of <0.05 was considered significant.

Results and Discussion

Soil Characteristics

Prior to manure application, mean measured soil 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) were 63, 3.8, 6, and 11 mg kg^{-1}, respectively. The soil at the study site had a mean EC of 0.47 dS m^{-1} and a pH of 7.7.

Measured mean values of NO_3-N and NH_4-N (obtained using a Lachat system from Zellweger Analytics, Milwaukee, Wisc.), TN (Bremner and Mulvaney, 1982), TP (Olsen and Sommers, 1982), water content (Gardner, 1986), EC, and pH for the manure were 0.01 g kg^{-1}, 0.26 g kg^{-1}, 15 g kg^{-1}, 4.1 g kg^{-1}, 83 g kg^{-1}, 19 dS m^{-1}, and 8.2, respectively. Manure and nutrient application rates are shown in table 1.

At the time of rainfall simulation testing, no significant cover by manure application rate interactions were found for soil measurements of Bray-1 P, water-soluble P, NO_3-N, NH_4-N, EC, or pH (table 2). Surface cover did not significantly affect any of the measured soil characteristics. However, manure application rate significantly affected measurements of Bray-1 P, water-soluble P, NO_3-N, and EC.

Soil measurements of Bray-1 P, water-soluble P, NO_3-N, and EC were significantly greater for the plots where manure was applied at a rate of 42.8 Mg ha^{-1} than for the other manure application rates. Measurements of EC varied from 0.71 dS m^{-1} on the plots where manure was applied at a rate of 42.8 Mg ha^{-1} to 0.41 dS m^{-1} on the control plots where manure was not added. Manure application rate did not significantly affect measurements of NH_4-N and pH.

Table 2. Effects of surface cover and manure application rate on selected soil characteristics.

		Bray-1 P (mg kg^{-1})	Water-Soluble P (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	EC (dS m^{-1})	pH
Cover	Cover	95	7.3	15.6	2.7	0.54	7.4
	No cover	91	6.3	14.0	2.6	0.50	7.4
Manure rate[a]	0	72 b	5.1 b	6.1 b	1.5	0.41 c	7.5
(Mg ha^{-1})	5.4	70 b	5.1 b	13.3 b	3.1	0.52 b	7.3
	10.7	82 b	5.5 b	13.1 b	3.6	0.50 bc	7.5
	21.4	75 b	6.3 b	11.0 b	1.8	0.48 bc	7.4
	42.8	168 a	11.8 a	30.4 a	3.4	0.71 a	7.3
Pr > F	Cover	0.72	0.21	0.60	0.88	0.25	0.91
	Rate	0.01	0.01	0.01	0.24	0.01	0.07
	Cover × Rate	0.99	0.97	0.21	0.56	0.65	0.40

[a] Beef cattle manure was applied to meet 0-, 1-, 2-, 4-, or 8-year P crop growth requirements for corn. Values followed by different letters are significantly different at the 0.05 probability level based on the LSD test.

Table 3. Runoff water quality parameters as affected by residue cover and manure application rate.[a]

		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)	Soil Loss (Mg ha^{-1})
Cover	Cover	0.17	0.09	0.26	1.20	0.014	1.64	0.74	7.88	21	0.15
	No cover	0.08	0.09	0.17	0.78	0.008	1.11	0.78	7.96	20	0.61
	LSD (0.05)	0.02		0.03	0.35	0.004	0.35	0.02	0.02		0.19
Manure rate[b] (Mg ha^{-1})	0	0.06	0.09	0.15	0.42	0.004	0.78	0.73	7.93	22	0.34
	5.4	0.08	0.08	0.16	0.88	0.014	1.32	0.76	7.91	22	0.35
	10.7	0.08	0.07	0.16	0.78	0.011	1.15	0.75	7.93	17	0.37
	21.4	0.16	0.08	0.23	1.23	0.011	1.55	0.77	7.92	19	0.41
	42.8	0.26	0.12	0.37	1.65	0.015	2.10	0.80	7.91	22	0.42
	LSD (0.05)	0.03		0.04	0.56	0.006	0.55	0.04		3	
ANOVA	Cover	0.01	0.85	0.01	0.03	0.01	0.01	0.01	0.01	0.95	0.01
	Rate	0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.73	0.01	0.98
	Cover × Rate	0.01	0.74	0.01	0.12	0.09	0.48	0.06	0.41	0.96	0.98

[a] Reported nutrient values represent the difference between runoff measurements and concentrations in the irrigation well water.
[b] Beef cattle manure was applied to meet 0-, 1-, 2-, 4-, or 8-year P crop growth requirements for corn.

Manure had been incorporated into the soil profile for six to ten weeks at the time the soil samples were collected. Additional mineralization of nutrients in manure would have occurred over time (Eghball et al., 2002). Therefore, the soil characteristics reported in this study are only representative of conditions expected at one point in time following manure application. The P content of soils that were disked following the application of manure were found by Gilley and Eghball (2002) to remain elevated after four years of corn production following the last application of beef cattle compost.

Runoff Characteristics

Water used in the rainfall simulation tests was obtained from an irrigation well. Reported nutrient values represent the difference between runoff measurements and concentrations in the irrigation water. Measured mean concentrations of DP, TP, NO_3-N, NH_4-N, and TN, in the irrigation water, obtained from a commercial laboratory, were: 0.17, 0.17, 13.6, 0.00, and 13.6 mg L^{-1}, respectively. The irrigation water had a mean EC of 0.79 dS m^{-1} and a pH of 7.6. The relatively large NO_3-N concentrations in the irrigation water are characteristic of wells in the area near fields that have been in long-term agricultural production.

Significant surface cover by manure application rate interactions were found for DP and TP (table 3). Surface cover significantly affected measurements of DP, TP, NO_3-N, NH_4-N, TN, EC, pH, and soil loss. Measurements of PP and runoff were not significantly influenced by surface cover. Manure application rate significantly affected measurements of DP, TP, NO_3-N, NH_4-N, TN, EC, and runoff. However, measurements of PP, pH, and soil loss were not significantly affected by manure application rate.

Phosphorus Measurements

The mean runoff load of DP was significantly larger for the plots with surface cover than for the plots without surface cover, with values measured as 0.17 and 0.08 kg ha^{-1}, respectively (table 3). In addition, the load of DP in runoff was larger for the plots with surface cover than without surface cover for each of the manure application rates (fig. 3). The differences in DP load on the plots with and without surface cover were most pronounced for the two largest manure application rates of 21.4 and 42.8 Mg ha^{-1}. The mean load of DP in runoff increased from 0.06 to 0.26 kg ha^{-1} as the manure application rate increased from 0 to 42.8 Mg ha^{-1} (table 3). The application of manure to meet a 2-year rather than a 1-year corn P requirement did not significantly increase DP load. However, application of manure to meet a 4-year P requirement resulted in a DP load that was significantly greater than that obtained for a 2-year P requirement. Regression equations were derived relating the DP loads in runoff (y) in kg ha^{-1} to manure application rate (x) in Mg ha^{-1}:

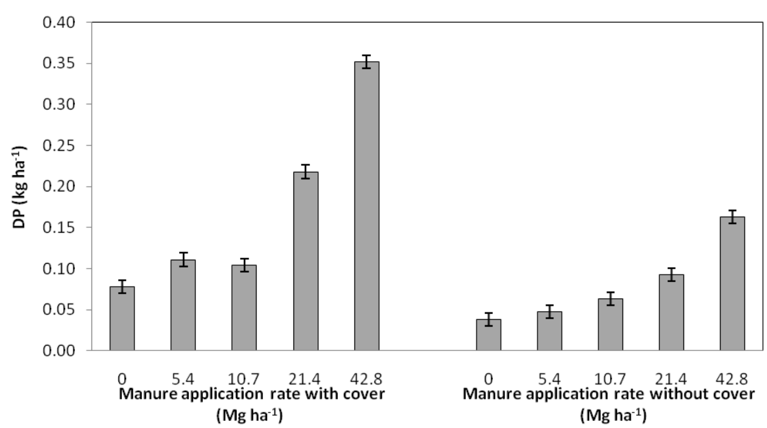

Figure 3. Dissolved phosphorus load (DP) as affected by manure application rate for sites with and without residue cover. Vertical bars are standard errors.

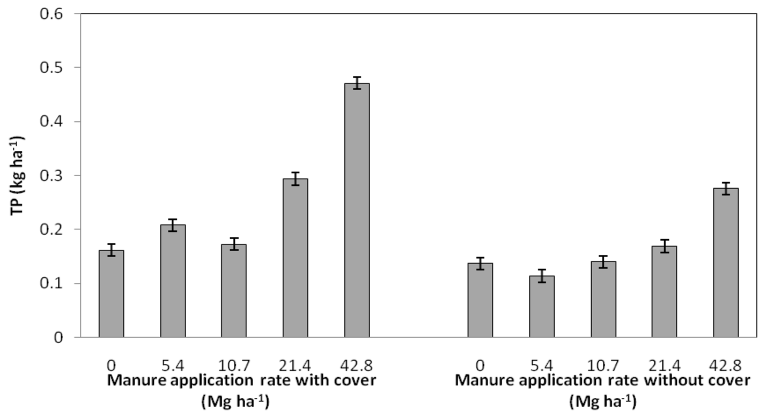

Figure 4. Total phosphorus load (TP) as affected by manure application rate for sites with and without residue cover. Vertical bars are standard errors.

For conditions with cover:

$$y = 0.0066x + 0.066 \ (R^2 = 0.97) \quad (1)$$

For no-cover conditions:

$$y = 0.003x + 0.033 \ (R^2 = 0.99) \quad (2)$$

The mean runoff load of TP for the plots with surface cover was significantly larger than for the plots without surface cover, with values measured as 0.26 and 0.17 kg ha^{-1}, respectively (table 3). Differences in TP load for the plots with and without surface cover were most pronounced for the two largest manure application rates of 21.4 and 42.8 Mg ha^{-1} (fig. 4). The mean load of TP in runoff increased from 0.15 to 0.37 kg ha^{-1} as the manure application rate increased from 0 to 42.8 Mg ha^{-1} (table 3). The application of manure to meet a 2-year rather than a 1-year corn P requirement did not significantly increase TP load. However, application of manure to meet a 4-year P requirement resulted in a TP load that was significantly larger than that obtained for a 2-year P requirement. Regression equations were derived relating the TP loads in runoff (y) in kg ha^{-1} to manure application rate (x) in Mg ha^{-1}:

For conditions with cover:

$$y = 0.0074x + 0.14 \ (R^2 = 0.95) \quad (3)$$

For no-cover conditions:

$$y = 0.0036x + 0.11 \ (R^2 = 0.91) \quad (4)$$

Nicolaisen et al. (2007) identified the effects of crop residue on nutrient concentrations in runoff from areas where beef cattle manure was applied to meet annual N requirements for corn but not incorporated. Existing residue materials were removed, and corn, soybean, or winter wheat residue was added at rates of 2, 4, or 8 Mg ha^{-1}. Three 30 min simulated rainfall events, separated by 24 h intervals, were conducted at an intensity of 70 mm h^{-1}. The concentration of DP in runoff was significantly greater for the treatments containing residue than for the no-residue treatments. However, no significant difference in TP concentration in runoff was found between the residue and no-residue treatments.

In the present study, DP and TP loads in runoff were both significantly greater for the cover treatments than for the no-cover treatments. The manure was incorporated in the present study immediately following application, and at least five weeks elapsed between manure application and the rainfall simulation tests. These factors may have contributed to the difference in TP transport between the study reported by Nicolaisen et al. (2007) and the present investigation.

Nitrogen Measurements

The mean runoff loads of NO_3-N, NH_4-N, and TN for the plots with surface cover were significantly larger than for the plots without surface cover, with values measured as 1.20, 0.014, and 1.64 kg ha^{-1}, compared to 0.78, 0.008, and 1.11 kg ha^{-1}, respectively (table 3). Manure application rate significantly affected nitrogen runoff loads. Runoff loads of NO_3-N varied from 0.42 to 1.65 kg ha^{-1}, NH_4-N loads ranged from 0.004 to 0.015 kg ha^{-1}, and runoff loads for TN varied from 0.78 to 2.10 kg ha^{-1}. Regression equations were derived relating the N loads in runoff (y) in kg ha^{-1} to manure application rate (x) in Mg ha^{-1}:

For NO_3-N:

$$y = 0.028x + 0.94 \ (R^2 = 0.91) \quad (5)$$

For TN:

$$y = 0.027x + 0.57 \ (R^2 = 0.92) \quad (6)$$

Nicolaisen et al. (2007) also identified the effects of crop residue on NO_3-N concentrations in runoff from areas where beef cattle manure was applied to meet annual N requirements for corn but not incorporated. The concentration of NO_3-N in runoff was significantly greater for the treatments containing residue than for the no-residue treatments. In the present study, the NO_3-N load in runoff was also significantly greater for the cover treatments than for the no-cover treatments.

EC, pH, Runoff, and Erosion Measurements

Measurements of EC were significantly larger on the plots without residue cover than on the plots with residue cover, with values measured as 0.78 and 0.74 dS m^{-1}, respectively (table 3). Measurements of EC increased significantly with manure application rate, with values varying from 0.73 to 0.80 dS m^{-1} as the manure application rate increased from 0 to 42.8 Mg ha^{-1}. The application of increased amounts of manure provided greater quantities of chemical constituents available for transport by overland flow. High levels of soluble salts in manure may be detrimental to crop growth if large amounts of manure are applied (Reynolds, 2006).

Table 4. Runoff water quality parameters as affected by residue cover, manure application rate, and runoff rate.[a]

		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})
Cover	Cover	10.2	13.3	23.5	43	0.85	161	0.77	7.72	33.5
	No cover	7.5	15.5	23.0	54	0.29	133	0.76	7.71	118.9
	LSD (0.05)	2.1				0.40		0.01		26.0
Manure rate[b] (Mg ha^{-1})	0	6.5	15.5	22.0	55	0.11	95	0.76	7.71	95.2
	5.4	5.8	11.6	17.4	50	0.70	164	0.76	7.70	56.0
	10.7	6.1	14.7	20.8	36	0.78	160	0.76	7.72	80.4
	21.4	9.9	12.2	22.1	26	0.87	114	0.77	7.72	70.3
	42.8	15.9	18.0	33.9	75	0.40	203	0.77	7.73	76.6
	LSD (0.05)	3.3		7.5	26					
Runoff rate (L min^{-1})	1.0	3.8	3.2	7.0	24	0.14	33	0.77	8.00	14.3
	2.2	4.3	4.6	8.9	20	0.32	39	0.76	7.78	17.1
	8.2	10.1	15.2	25.3	50	0.99	181	0.76	7.65	69.3
	12.2	11.5	18.2	29.7	61	0.73	204	0.76	7.58	102.3
	19.5	14.6	30.8	45.4	86	0.67	279	0.76	7.57	175.4
	LSD (0.05)	1.7	3.3	4.1	20	0.37	68		0.02	26.1
ANOVA	Cover	0.02	0.19	0.86	0.20	0.01	0.58	0.04	0.51	0.01
	Manure rate	0.01	0.14	0.01	0.02	0.15	0.66	0.26	0.83	0.47
	Runoff rate	0.01	0.01	0.01	0.01	0.01	0.01	0.45	0.01	0.01
	Cover × Manure rate	0.14	0.12	0.26	0.17	0.22	0.35	0.12	0.88	0.57
	Cover × Runoff rate	0.01	0.26	0.01	0.01	0.06	0.80	0.01	0.01	0.01
	Manure rate × Runoff rate	0.01	0.27	0.13	0.24	0.21	0.85	0.08	0.96	0.58
	Cover × Manure rate × Runoff rate	0.75	0.51	0.44	0.82	0.63	0.43	0.65	0.62	0.71

[a] Reported nutrient values represent the difference between runoff measurements and concentrations in the irrigation well water.
[b] Beef cattle manure was applied to meet 0-, 1-, 2-, 4-, or 8-year P crop growth requirements for corn.

Measurements of pH were significantly larger on the plots without residue cover than on the plots with residue cover (table 3). Manure application rate did not significantly affect pH measurements, which varied from 7.91 to 7.93.

Water was added to the plot surfaces before initiation of the rainfall simulation tests to maintain uniform antecedent soil water conditions. As a result, surface cover did not significantly affect runoff measurements. The rainfall application rate during the 30 min rainfall event was approximately 35 mm, while the mean runoff rate was 21 mm (table 3). Therefore, 14 mm infiltrated during the 30 min rainfall simulation period on the silty clay soil used in this study. A final infiltration rate of 10 to 20 mm h^{-1} was reported by Hillel (1971) for sandy and silty soils.

The presence of surface cover significantly reduced soil loss from 0.61 to 0.15 Mg ha^{-1}. Surface cover serves to reduce both the detachment and transport of soil particles. The effectiveness of surface cover in reducing soil loss is well documented (Gilley et al., 1986a, 1986b).

Runoff Characteristics as Affected by Runoff Rate

For a given plot, water quality measurements obtained from each of the three rainfall simulation runs were included in the analyses and were treated as repeated measures. Significant surface cover by runoff rate interactions were found for DP, TP, NO_3-N, EC, pH, and soil loss (table 4). A significant manure application rate by runoff rate interaction was found for DP. Surface cover significantly affected measurements of DP, NH_4-N, EC, and soil loss. Manure application rate significantly affected measurements of DP, TP, and NO_3-N. Each of the measured water quality parameters except EC was significantly affected by runoff rate.

Phosphorus Measurements

The mean runoff load of DP for the plots with surface cover was significantly larger than for the plots without surface cover, with values measured as 10.2 and 7.5 g ha^{-1} min^{-1}, respectively (table 4). No significant differences in DP load were found among runoff rates of 8.34, 12.32, and 19.12 L min^{-1} for the plots containing surface cover (fig. 5). In contrast, DP load for the plots without surface cover increased significantly as the runoff rate increased from 8.02 to 19.96 L min^{-1} (fig. 5). The mean load of DP in runoff increased from 5.8 to 15.9 g ha^{-1} min^{-1} as the manure application rate increased from 5.4 to 42.8 Mg ha^{-1} (table 4). The mean runoff load of DP consistently increased from 3.8 to 14.6 g ha^{-1} min^{-1} as the runoff rate increased from 1.0 to 19.5 L min^{-1}. Regression equations were derived relating the rate of transport of DP in runoff (y) in g ha^{-1} min^{-1} to runoff rate (x) in L min^{-1}:

For conditions with cover:

$$y = 0.49x + 6.01 \quad (R^2 = 0.80) \qquad (7)$$

For no-cover conditions:

$$y = 0.71x + 1.36 \quad (R^2 = 0.99) \qquad (8)$$

Manure application rate significantly affected the transport of TP in runoff, with measured values varying from 17.4 to 33.9 g ha^{-1} min^{-1} as the manure application rate increased from 5.4 to 42.8 Mg ha^{-1} (table 4). No significant difference in TP load was found between the first two flow rates for the plots with and without surface cover (fig. 6). However, the TP load of runoff at the largest runoff rate was significantly greater for the plots without surface cover than for the plots

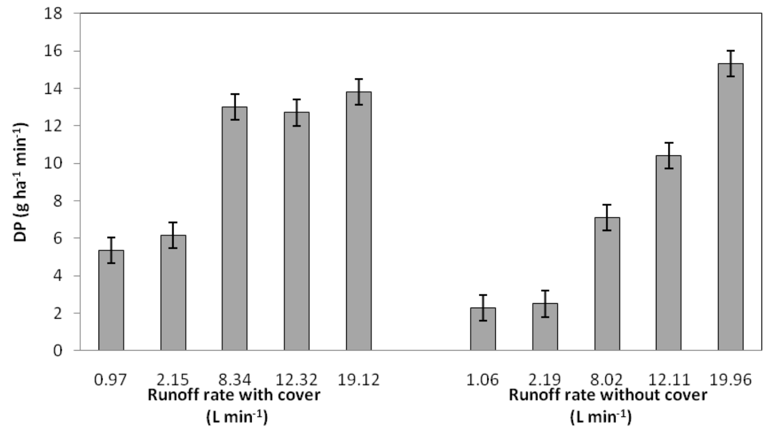

Figure 5. Rate of transport of dissolved phosphorus (DP) in runoff as affected by runoff rate for sites with and without residue cover. Vertical bars are standard errors.

with surface cover. Regression equations were derived relating the rate of transport of TP in runoff (y) in g ha^{-1} min^{-1} to runoff rate (x) in L min^{-1}:

For conditions with cover:

$$y = 1.81x + 7.92 \ (R^2 = 0.96) \quad (9)$$

For no-cover conditions:

$$y = 2.32x + 2.91 \ (R^2 = 0.99) \quad (10)$$

Gilley et al. (2008b) measured the effects of overland flow rate on runoff nutrient transport following the application of beef cattle manure to plots containing 0, 2, 4, or 8 Mg ha^{-1} of corn residue. Inflow was added to the top of each plot to produce runoff rates varying from 3.11 to 15.9 kg min^{-1}. The rate of transport of DP, PP, and TP were each found to be significantly affected by runoff rate. Runoff rate was also found in the present study to significantly affect the rate of transport of DP, PP, and TP.

Nitrogen Measurements

No significant differences in NO_3-N loads in runoff were found for manure application rates varying from 5.4 to 21.4 Mg ha^{-1} (table 4). For the plots with residue cover, no significant differences in runoff loads of NO_3-N were found for runoff rates varying from 8.34 to 19.12 L min^{-1} (fig. 7). However, NO_3-N runoff loads for the plots without residue cover increased significantly as the runoff rate increased from 8.02 to 19.96 L min^{-1}. Regression equations were derived relating the rate of transport of NO_3-N in runoff (y) in g ha^{-1} min^{-1} to runoff rate (x) in L min^{-1}:

For conditions with cover:

$$y = 1.71x + 28.1 \ (R^2 = 0.90) \quad (11)$$

For no-cover conditions:

$$y = 5.35x + 7.51 \ (R^2 = 0.99) \quad (12)$$

Runoff loads of NH_4-N were much smaller than NO_3-N loads (table 4). The runoff load of NH_4-N was significantly larger for the plots with surface cover than for the plots without surface cover, with values measured as 0.85 and 0.29 g ha^{-1} min^{-1}, respectively. Runoff loads of NH_4-N were significantly affected by runoff rate, with measured values varying from 0.14 to 0.99 g ha^{-1} min^{-1}.

The load of TN in runoff was not significantly affected by residue cover or manure application rate (table 4). However, runoff rate significantly affected TN loads in runoff. The load of TN in runoff consistently increased with each runoff increment and varied from 33 to 279 g ha^{-1} min^{-1} as the runoff rate increased from 1.0 to 19.5 L min^{-1}. A regression equation was

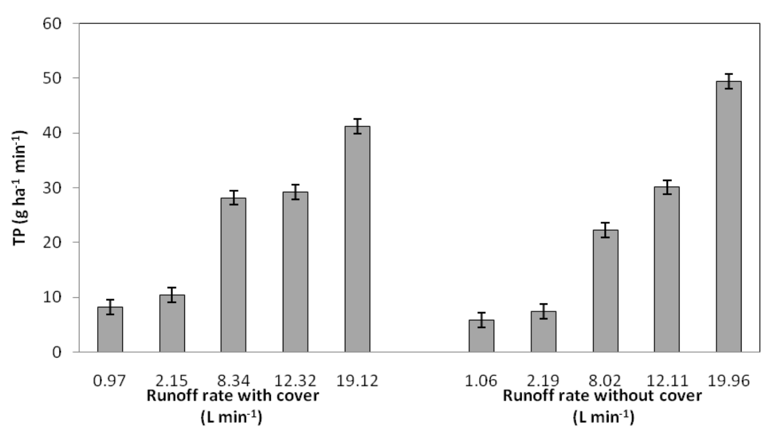

Figure 6. Rate of transport of total phosphorus (TP) in runoff as affected by runoff rate for sites with and without residue cover. Vertical bars are standard errors.

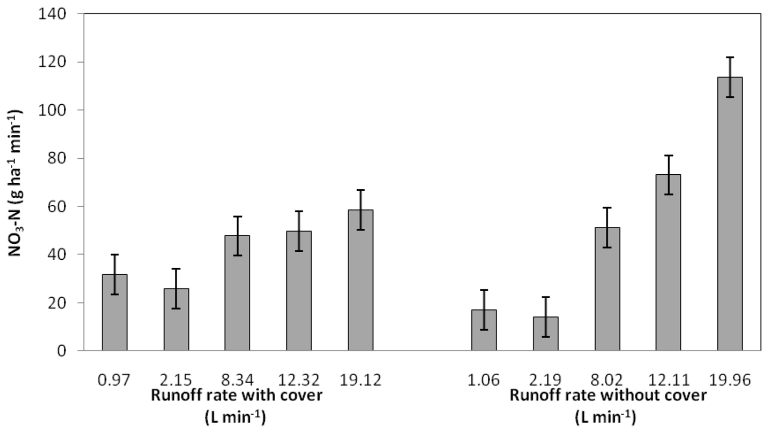

Figure 7. Rate of transport of NO_3-N in runoff as affected by runoff rate for sites with and without residue cover. Vertical bars are standard errors.

derived relating the rate of transport of TN in runoff (y) in g ha^{-1} min^{-1} to runoff rate (x) in L min^{-1}:

$$y = 13.8x + 28.1 \ (R^2 = 0.95) \tag{13}$$

Nicolaisen et al. (2007) also identified the effects of crop residue on NO_3-N concentrations in runoff from areas where beef cattle manure was applied to meet annual N requirements for corn but not incorporated. The concentration of NO_3-N in runoff was significantly greater for the treatments containing residue than for the no-residue treatments. In the present study, the NO_3-N load in runoff was significantly greater for the cover treatment than for the no-cover treatment.

Gilley et al. (2008b) also measured the effects of overland flow rate on runoff nutrient transport following the application of beef cattle manure to plots containing selected amounts of corn residue. The rate of transport of NO_3-N, NH_4-N, and TN were each found to be significantly affected by runoff rate. Runoff rate was also found in the present study to significantly affect the rate of transport of NO_3-N, NH_4-N, and TN.

EC, pH, and Soil Loss Measurements

The EC of runoff for the cover and no-cover conditions was 0.77 and 0.76 dS m^{-1}, respectively (table 4). Manure application rate did not significantly affect EC measurements. A runoff EC value of 0.76 dS m^{-1} was measured for each of the four inflow increments where overland flow was introduced.

Measurements of pH were not significantly affected by surface cover or manure application rate (table 4). However, runoff rate significantly influenced pH measurements, with values decreasing from 8.00 to 7.57 as the runoff rate increased from 1.0 to 19.5 L min^{-1}.

The presence of surface cover significantly reduced soil loss from 118.9 to 33.5 g ha^{-1} min^{-1} (table 4). Soil loss increased significantly with runoff rate, with measurements varying from 14.3 to 175.4 kg ha^{-1} min^{-1} as the runoff rate increased from 1.0 to 19.5 L min^{-1}.

CONCLUSIONS

Manure is applied to cropland areas managed using a variety of cropping and tillage conditions that result in varying amounts of crop residue. In this study, the mean runoff loads of DP and TP for the plots with residue cover were 0.17 and 0.26 kg ha^{-1}, which were significantly greater than the values of 0.08 and 0.17 kg ha^{-1} measured for the plots without residue cover. The mean runoff loads of NO_3-N, NH_4-N, and TN for the plots with residue cover were 1.20, 0.014, and 1.64 kg ha^{-1}, which were significantly greater than the values of 0.78, 0.008, and 1.11 kg ha^{-1} measured for the plots without residue cover.

Manure can be applied to meet multiple-year crop nutrient requirements. However, increasing the amount of manure that is applied to cropland areas may also result in increased runoff nutrient loads. Because of residual soil nutrients, no significant differences in runoff loads of DP, TP, or NO_3-N were found among the plots where manure was applied to meet 0-, 1-, or 2-year P corn requirements. However, runoff loads of DP, TP, and NO_3-N increased significantly when manure was applied to meet a 4-year P corn requirement.

Each of the measured runoff water quality parameters except EC was significantly influenced by runoff rate. Runoff loads for DP, TP, NO_3-N, and NH_4-N increased in a linear fashion with runoff rate. Residue cover, manure application rate, and runoff rate should each be considered when estimating runoff nutrient loads from land application areas.

REFERENCES

Andraski, T. W., and L. G. Bundy. 2003. Relationships between phosphorus levels in soil and in runoff from corn production systems. *J. Environ. Qual.* 32(1): 310-316.

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

Bremer, V. R., R. K. Koelsch, R. E. Massey, and G. E. Erickson. 2007. Effects of distillers grain and manure management on nutrient management plans and economics. 2008 Nebraska Beef Report. Misc. Publication No. 91. Lincoln, Neb.: University of Nebraska Cooperative Extension.

Bremner, J. M., and C. S. Mulvaney. 1982. Nitrogen-total. In *Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties*, 595-624. Agronomy Monograph No. 9. Madison, Wisc.: ASA.

Eghball, B., B. J. Wienhold, J. E. Gilley, and R. A. Eigenberg. 2002. Mineralization of manure nutrients. *J. Soil Water Cons.* 57(6): 470-473.

Gardner, W. H. 1986. Water content. In *Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods*, 493-544. Agronomy Monograph No. 9. Madison, Wisc.: ASA.

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., S. C. Finkner, and G. E. Varvel. 1986a. Runoff and erosion as affected by sorghum and soybean residue. *Trans. ASAE* 29(6): 1605-1610.

Gilley, J. E., S. C. Finkner, R. G. Spomer, and L. N. Mielke. 1986b. Runoff and erosion as affected by corn residue: Part I. Total losses. *Trans. ASAE* 29(1): 157-160.

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

Gilley, J. E., B. Eghball, and D B Marx. 2008a. Narrow grass hedge effects on nutrient transport following compost application. *Trans. ASABE* 51(3): 997-1005.

Gilley, J. E., W. F. Sabatka, B. Eghball, and D. B. Marx. 2008b. Nutrient transport as affected by rate of overland flow. *Trans. ASABE* 51(4): 1287-1293.

Hillel, D. 1971. *Soil and Water Physical Principles and Processes.* New York, N.Y.: Academic Press.

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*, 26-78. Bulletin No. 766. Berkeley, Cal.: University of California, Agricultural Experiment Station.

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.

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.

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.

Olsen, S. R., and L. E. Sommers. 1982. Phosphorus. In *Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties*, 403-430. Agronomy Monograph No. 9. Madison, Wisc.: ASA.

Reynolds, M. A. 2006. Managing livestock manure to protect environmental quality. EC-02-179. Lincoln, Neb.: University of Nebraska Cooperative Extension.

SAS. 2003. *SAS/STAT User's Guide.* Version 9. Vol. 1. 4th ed. Cary, N.C.: 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: 829-839.