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Crop Residue Effects on Runoff Nutrient Concentrations Following Manure Application

Jeffrey E. Nicolaisen
Environmental Resource Management, Inc., Appleton, Wisconsin

John E. Gilley
University of Nebraska - Lincoln, john.gilley@ars.usda.gov

Bahman Eghball
University of Nebraska - Lincoln

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

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CROP RESIDUE EFFECTS ON RUNOFF NUTRIENT CONCENTRATIONS FOLLOWING MANURE APPLICATION

J. E. Nicolaisen, J. E. Gilley, B. Eghball, D. B. Marx

ABSTRACT. *Manure is applied to cropland areas managed under diverse conditions, resulting in varying amounts of residue cover. The objective of this study was to measure the effects of crop residue on nutrient concentrations in runoff from areas where beef cattle or swine manure were recently applied but not incorporated. Plots 0.75 m wide by 2 m long were established at the study site. Existing residue materials were removed, and corn, soybean, or winter wheat residue was added at rates of 2, 4, or 8 Mg* ha^{-1}*. Manure was then applied at rates required to meet estimated annual nitrogen requirements for corn. Control plots with manure but no residue, and plots with no residue and no manure were also established. Three 30 min simulated rainfall events, separated by 24 h intervals, were conducted at an intensity of approximately 70 mm* h^{-1}*. Dissolved phosphorus (DP), total phosphorus (TP),* NO_3*–N,* NH_4*–N, total nitrogen, runoff, and soil loss were measured for each rainfall event. When beef cattle or swine manure was applied to plots containing residue materials, nutrient concentrations in runoff were not affected by the amount of crop residue on the soil surface. Concentrations of DP and* NO_3*–N in runoff from the plots with beef cattle manure were significantly greater on the plots with residue than on the no-residue treatments. No significant differences in runoff nutrient concentrations were found between the residue and no-residue treatments with swine manure. Concentrations of DP and TP were significantly less on the no-residue/no-manure treatment than on the plots with beef cattle or swine manure.*

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

Manure contains nutrients that can serve as a substitute for inorganic fertilizer and organic matter that can improve soil characteristics including infiltration, porosity, and water holding capacity. However, nutrients in runoff from agricultural areas may cause adverse environmental impacts (Sharpley et al., 1994, 2000; Andraski and Bundy, 2003). Source factors such as manure or fertilizer application method, loading rate, and soil nutrient test level affect runoff nutrient concentrations (Sims, 1993; Daniel et al., 1994; McDowell et al., 2001). Transport factors including runoff and erosion may influence nutrient delivery by surface runoff (Lemunyon and Gilbert, 1993; Gilley et al., 2001). The length of time that has elapsed since manure application can also affect runoff nutrient concentrations (Gilley and Eghball, 2002). Soil nutrient values may not significantly impact runoff nutrient concentrations when rainfall occurs soon after manure application (Eghball et al., 2002).

Reduced tillage systems help to maintain crop residue on the soil surface. Doran and Linn (1994) cite several benefits of no-till farming systems including soil protection from erosion losses, conservation of soil water by increased infiltration and decreased evaporation, greater use of land too steep for conventional tillage, and reduction in fuel, labor, and machinery costs. The application of manure to a no-till system without incorporation can result in DP concentrations in runoff that exceed established water quality standards (Eghball and Gilley, 1999). Maintenance of residue cover is an important concern when reduced tillage systems are used. There have been few studies examining the effects of crop residue on runoff nutrient concentrations from sites on which manure was recently added. The objective of this study was to measure the effects of crop residue on nutrient concentrations in runoff from areas where beef cattle or swine manure were recently applied but not incorporated.

MATERIALS AND METHODS

STUDY SITE CHARACTERISTICS AND EXPERIMENTAL DESIGN

This field study was conducted from May to August 2001 at the University of Nebraska Rogers Memorial Farm located about 18 km east of Lincoln, Nebraska, in Lancaster County. The Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) at the site contained 11% sand, 54% silt, and 35% clay, and 18.5 g kg^{-1} organic C in the top 15 cm of soil. The soil formed from loess under prairie vegetation and had

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The authors are **Jeffrey E. Nicolaisen,** Staff Engineer, Environmental Resource Management, Inc., Appleton, Wisconsin; **John E. Gilley, ASABE Member Engineer,** Agricultural Engineer, USDA-ARS, University of Nebraska, Lincoln, Nebraska; **Bahman Eghball,** Soil Scientist (deceased), USDA-ARS, Lincoln, Nebraska; and **David B. Marx,** Professor, University of Nebraska, Lincoln, Nebraska. **Corresponding author:** John E. Gilley, USDA-ARS, Room 251, Chase Hall, University of Nebraska, Lincoln, NE 68583-0934; phone: 402-472-2975; fax: 402-472-6338; e-mail: John.Gilley@ars.usda.gov.

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] (d S m^{-1})	pH
0-5	9.4	72.5	8.4	5.0	0.4	6.6
5-15	0.7	7.1	4.7	4.9	0.3	5.3

[a] WSP = water soluble P, and BKP = Bray and Kurtz No. 1 phosphorus.
[b] EC = electrical conductivity. EC and pH were determined in 1:1 soil/water ratio (Smith and Doran, 1996).

a mean slope of 7%. Soil characteristics at the study site are shown in table 1. 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 left undisturbed following soybean harvest in the fall of 2000. Herbicide was applied immediately before and midway through the study to prevent weed growth.

Tests using beef cattle (*Bos taurus*) and swine (*Sus scrofa*) manure were conducted on separate blocks each containing 33 plots. The types and amounts of crop residue applied within each block varied in a randomized design. Each block included three replications of corn (*Zea mays* L.), soybean, or winter wheat residue applied at rates of 2, 4, or 8 Mg ha^{-1} (27 plots). In addition, a treatment without crop residue but with manure (3 plots) and a treatment without crop residue or manure (3 plots) were included in the 33 plots contained in each block. Thus, a total of 66 plots were examined during this study.

Corn and soybean residue used in this investigation were collected in May 2001 at the Rogers Memorial Farm. The winter wheat straw was obtained from a commercial source and was bailed soon after harvest. The crop residue materials were dried in an oven at 60°C and then stored for future use. The drying process allowed the residue materials to be applied on a uniform dry weight basis.

Equations have been developed that allow surface cover to be estimated from residue mass. A residue mass of 2, 4, or 8 Mg ha^{-1} provides approximately the following surface cover: 20%, 37%, and 60% with corn (Gilley et al., 1986b); 24%, 42%, and 66% with soybean (Gilley et al., 1986a); and 63%, 86%, and 98% with wheat (Gregory, 1982). 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.

MANURE CHARACTERISTICS

Beef cattle manure was collected in May 2001 from a private confined livestock operation near Waterloo, Nebraska. To provide greater application uniformity, larger-size materials were broken by hand and the manure was sieved through a screen with 12 mm openings. The beef cattle manure was then placed in plastic bags and stored at 4°C until it was applied.

Swine manure was obtained in June 2001 from the University of Nebraska Agricultural Research and Development Center near Ithaca, Nebraska. The liquid swine manure was collected from a pit located below a slatted floor and was stored in 19 L plastic pails. The plastic pails with lids were kept at air temperature in a shed until they were needed. The production unit had been in operation for two months and contained 100 swine weighing 36 to 45 kg that were fed a corn-soybean diet.

Beef cattle and swine manure were applied at rates of 32.3 and 66.5 Mg ha^{-1}, respectively, the approximate amounts required to meet estimated corn N requirements. Application rates were determined using 40% N availability for beef cattle manure (Eghball and Power, 1999) and 70% N availability for swine manure (Gilbertson et al., 1979). Table 2 lists manure characteristics reported from replicated samples sent to a commercial laboratory, and application rates of nitrogen (N) and phosphorus (P).

RAINFALL SIMULATION PROCEDURES

Water used in the rainfall simulation tests was obtained from an irrigation system. Measured mean concentrations of DP, TP, NO_3–N, NH_4–N, and total N (TN) in the irrigation water were: 0.22, 0.22, 17.8, 0.02, and 17.8 mg L^{-1}, respectively. The irrigation water had a mean EC value of 0.73 dS m^{-1} and a pH of 7.62. Reported nutrient concentrations represent the difference between runoff measurements and concentrations in the irrigation well water.

Paired 0.75 m wide by 2 m long plots were established. The plots were raked, and any remaining plant material was removed by hand. Burlap material was placed on the plots to reduce surface disturbance during the prewetting process. To provide more uniform antecedent soil water conditions between treatments, water was applied to the plots with a hose until runoff began. Crop residue and then manure were added by hand following the pre-wetting process.

Rainfall simulation procedures adopted by the National Phosphorus Research Project (NPRP) were employed in this study (Sharpley and Kleinman, 2003). Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the paired plots. A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall for 30 min at an intensity of approximately 70 mm h^{-1}. Two additional rainfall simulation runs were conducted at approximately 24 h intervals. Plots were covered with tarps between simulation events to prevent the input of natural rainfall.

Sheet metal borders channeled runoff into a collection trough. The trough extended across the bottom of each plot and diverted runoff into aluminum washtubs. Runoff was agitated to maintain suspension of solids and then sampled.

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

	Concentrations[a]							Applied	
Manure	NO_3–N (g kg^{-1})	NH_4–N (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Water Content (g kg^{-1})	EC[b] (d S m^{-1})	pH	Total N (kg ha^{-1})	Total P (kg ha^{-1})
Beef cattle	0.0047	0.12	8.16	3.22	302	5.6	8.4	264	104
Swine	0.0001	2.25	3.25	0.76	989	13.9	6.9	216	22

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

Table 3. Analysis of variance (PR > F) showing the effects of residue type, residue amount, and manure application on water quality, runoff and erosion characteristics.

Variable	DP	Total P	NO_3–N	NH_4–N	Total N	Runoff	Erosion
Beef cattle manure							
Residue type	0.04	0.64	0.72	0.49	0.60	0.14	0.94
Residue amount	0.30	0.30	0.12	0.66	0.73	0.06	0.43
Residue type × amount	0.82	0.58	0.47	0.77	0.90	0.71	0.55
No residue – manure	0.05	0.65	0.04	0.16	0.83	0.72	0.48
No residue – no manure	0.01	0.01	0.01	0.66	0.41	0.70	0.80
Swine manure							
Residue type	0.44	0.09	0.56	0.05	0.48	0.49	0.41
Residue amount	0.80	0.08	0.21	0.51	0.33	0.04	0.09
Residue type × amount	0.23	0.06	0.28	0.15	0.13	0.35	0.57
No residue – manure	0.71	0.01	0.76	0.15	0.56	0.48	0.01
No residue – no manure	0.01	0.01	0.17	0.01	0.14	0.29	0.27

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). Runoff samples were dried in an oven at 105°C and weighed to determine sediment content.

STATISTICAL ANALYSES

Physical and chemical characteristics of the beef cattle and swine manure were substantially different. As a result, separate statistical analyses were preformed on data collected from the beef cattle and swine manure treatments. Measurements from the three rainfall simulation runs were treated as repeated measures. Analysis of variance was performed to identify the effects of residue type, residue amount, and manure application on selected water quality, runoff, and erosion characteristics. The least significant difference test was used to determine statistical significance among treatment means. A probability level < 0.05 was considered significant.

RESULTS AND DISCUSSION

BEEF CATTLE MANURE TREATMENTS

The residue type × residue amount interaction was not significant for any of the water quality, runoff, or erosion characteristics measured on the plots with beef cattle manure (table 3). For the plots containing residue and manure, the amount of residue on the soil surface did not significantly affect nutrient concentrations in runoff (table 3). However, significant differences in concentrations of DP and NO_3–N were found between the residue and no-residue treatments with beef cattle manure (figs. 1a and 1c). Concentrations of DP, TP, and NO_3–N in runoff were significantly less on the plots with no residue and no manure than the treatments with beef cattle manure (figs. 1a, 1b, and 1c). Runoff concentrations of NH_4–N and TN for the 33 plots on the beef cattle manure experimental block averaged 0.70 and 55.3 mg L^{-1}, respectively.

Hydraulic roughness coefficients are greater on areas containing crop residue (Gilley et al., 1991). As a result, overland flow runoff velocities may be reduced on sites with substantial residue cover. In addition, small ponds created by crop residue serve to store water on upland areas (Gilley and Kottwitz, 1994). The cumulative volume of water generated by a large number of ponds can be substantial. The reduced runoff velocity and ponding of water caused by crop residue could have increased leaching of DP and NO_3–N from the beef cattle manure.

Water was added to the plots before initiation of the rainfall simulation tests to provide more uniform antecedent soil water conditions among plots. Since soil near the surface was close to saturation when the rainfall simulation tests were initiated, no significant differences in total runoff were measured between the residue and no-residue treatments (table 3). Consequently, results related to nutrient concentration should also be applicable to nutrient load. A mean runoff value of 18 mm was measured for the 33 plots on the beef cattle manure experimental block.

No significant differences in soil erosion measurements were found among the experimental treatments on the beef cattle manure experimental block. The reduced erodibility expected under no-till conditions appears to have been maintained even after the existing residue materials had been removed. For the 33 plots on the beef cattle manure experimental block, a mean soil erosion value of 0.29 Mg ha^{-1} was measured. Gilley and Eghball (1998) also found that runoff and erosion from simulated rainfall were not significantly influenced by the single application of beef cattle manure.

SWINE MANURE TREATMENTS

For the plots with swine manure, the residue type × residue amount interaction was not significant for any of the measured water quality, runoff, or erosion characteristics (table 3). The amount of residue on the soil surface did not significantly affect nutrient concentrations in runoff on the plots containing residue and manure (table 3). No significant differences in nutrient concentrations were found between the residue and no-residue treatments with swine manure (table 3, figs. 2a through 2d). Concentrations of DP, TP, and NH_4–N in runoff were significantly less on the plots with no residue and no manure (figs. 2a, 2b, and 2c). For the 33 plots on the swine manure experimental block, mean concentrations of NO_3–N and TN were 0.55 and 106 mg L^{-1}, respectively.

No significant differences in total runoff amounts were measured between the residue and no–residue treatments (table 3) on the swine manure experimental block. A mean runoff value of 22 mm was measured. For the plots with residue and manure, a mean erosion value of 0.48 Mg ha^{-1} was obtained, compared to 0.95 and 0.68 Mg ha^{-1} on the no–

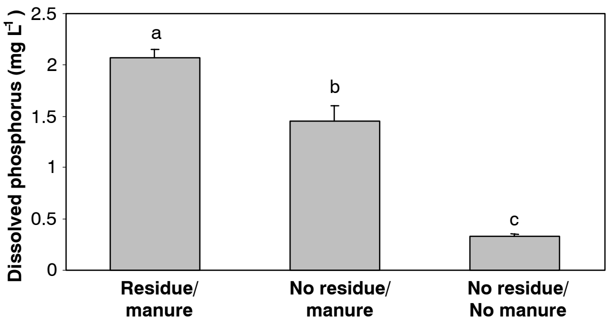

Figure 1a. Dissolved phosphorus in runoff as affected by crop residue and cattle manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

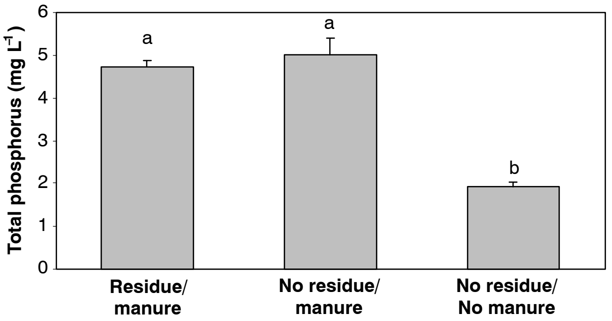

Figure 1b. Total phosphorus in runoff as affected by crop residue and cattle manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

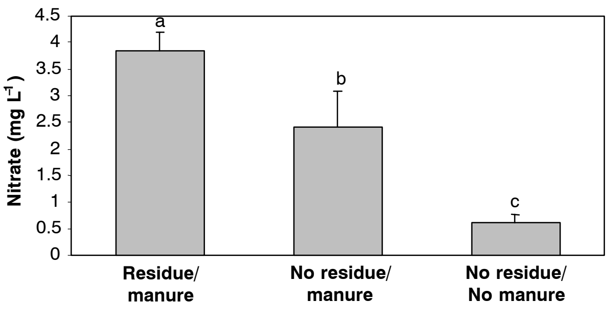

Figure 1c. Nitrate in runoff as affected by crop residue and cattle manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

residue/manure and no–residue/no–manure treatments, respectively (fig. 2d).

Additional Considerations

The rainfall simulation and data collection protocols adopted by the NPRP (Sharpley and Kleinman, 2003) were used in this study. However, it is recognized that these procedures represent an extreme condition. Three consecutive high-intensity storms, each of 30 min duration, would not be expected to occur over a 72 h period under natural rainfall conditions. Adding water to the plots prior to the tests to provide more uniform antecedent soil water conditions enhanced the opportunity for runoff.

Rainfall simulation tests were conducted soon after manure was applied. In this study, manure was not incorporated

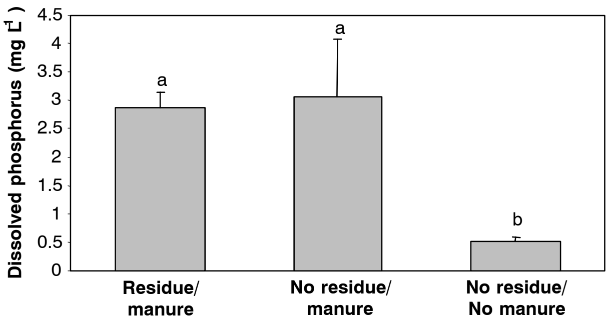

Figure 2a. Dissolved phosphorus in runoff as affected by crop residue and swine manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

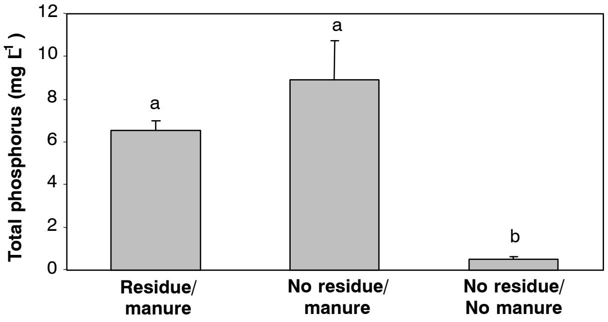

Figure 2b. Total phosphorus in runoff as affected by crop residue and swine manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

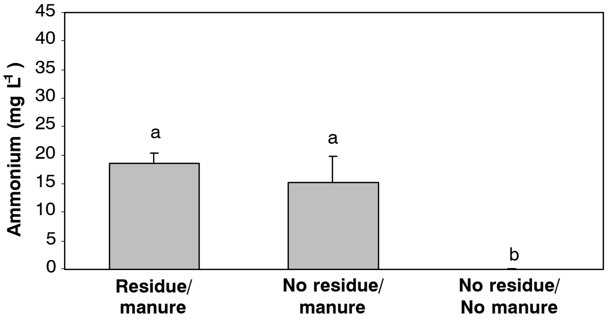

Figure 2c. Ammonium in manure as affected by crop residue and swine manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

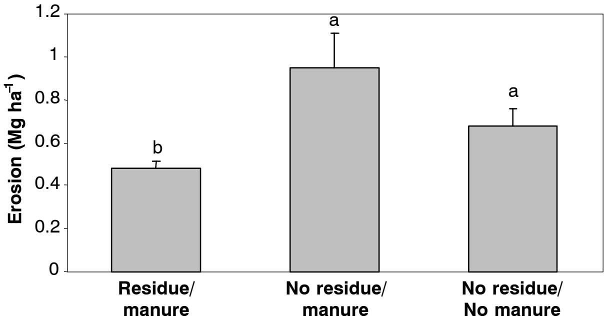

Figure 2d. Erosion as affected by crop residue and swine manure. Vertical bars are standard errors. The letter above each bar indicates statistical significance at $P < 0.05$ using the least significant difference test.

or injected. The incorporation of manure following application can significantly reduce the concentration of nutrients in runoff (Eghball and Gilley, 1999). Little information is currently available concerning temporal changes in nutrient transport following the addition of beef cattle or swine manure to cropland areas.

Manure has been effectively used to improve crop production and soil properties because it contains nutrients and organic matter. In this study, runoff and erosion were measured soon after manure application. For selected locations on which manure was added annually, runoff was reduced from 2% to 62%, and soil loss decreased from 15% to 65% compared to non-manured sites (Gilley and Risse, 2000).

Crop residues on the soil surface subjected to rainfall have been found to be a significant source of soluble nutrients in agricultural runoff (Schreiber, 1985). As residue decomposed, the fraction of water-soluble NO_3-N in plant material that was leached under rainfall was reported to increase (Havis and Alberts, 1993). Significant amounts of PO_4-P and NH_4-N were also found in leachate from corn residue (Schreiber, 1999). Nutrient concentrations in leachate were greater at lower rainfall intensities and higher corn residue loading rates. For individual storms, NO_3-N concentrations in leachate rapidly decreased with either time or cumulative leachate volume to a near constant value. Little information is currently available concerning temporal changes in the leaching of nutrients from crop residue materials.

Concentrations of human health-related microorganisms in runoff from the experimental plots established in this study were also measured. Additional details concerning the microbial tests are provided by Thurston-Enriquez et al. (2005).

CONCLUSIONS

The amount of crop residue found on a site cropped under no-till conditions did not significantly affect nutrient concentrations in runoff on the treatments with residue and beef cattle manure applied directly on the surface. However, significant differences in concentrations of DP and NO_3-N were found between the residue and no-residue treatments with beef cattle manure. Concentrations of DP, TP, and NO_3-N in runoff were significantly less on the plots with no residue and no manure than the treatments with beef cattle manure. Runoff concentrations of NH_4-N and TN for the 33 plots on the beef cattle manure experimental block averaged 0.70 and 55.3 mg L^{-1}, respectively.

On the plots containing residue and swine manure and cropped under no-till conditions, the amount of residue on the soil surface did not significantly affect nutrient concentrations in runoff. No significant differences in nutrient concentrations were found between the residue and no-residue treatments with swine manure. Concentrations of DP, TP, and NH_4-N in runoff were significantly less on the plots with no residue and no manure. For the 33 plots on the swine manure experimental block, mean concentrations of NO_3-N and TN were 0.55 and 106 mg L^{-1}, respectively.

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