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Narrow Grass Hedge Effects on Microbial Transport Following Variable Applications of Beef Cattle Manure

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Abstract. *The effectiveness of a 1.4 m wide grass hedge in reducing microbial transport following manure application was examined in this study. Beef cattle manure was applied to 0.75 m wide by 4.0 m long plots established on an Aksarben silty clay loam located in southeast Nebraska. Manure was added at rates required to meet none or the 1-, 2-, or 4-year nitrogen requirements for corn. The transport of phages, total coliforms,* E. coli*, and enterococci was measured for three 30 min simulated rainfall events, which were separated by approximately 24 h intervals. The narrow grass hedge reduced total counts of phages,* E. coli*, and enterococci from 10.8 to 9.01 log PFU ha^{-1}, from 12.4 to 11.9 log CFU ha^{-1}, and from 11.8 to 11.2 log CFU ha^{-1}, respectively. For the plots that received manure, no significant differences in transport of phages or enterococci were found among the three manure application rates. Rainfall simulation run significantly affected measurements of phages, total coliforms, and enterococci, with measurements during the three runs varying from 8.91 to 10.5 log PFU ha^{-1}, from 12.7 to 13.3 log CFU ha^{-1}, and from 11.2 to 11.7 log CFU ha^{-1}, respectively. Counts for phages, total coliforms, and enterococci were significantly less for the first than the second and third rainfall simulation runs. All four of the microbial constituents were significantly correlated to dissolved P, particulate P, total P, and total N. A narrow grass hedge placed on the contour significantly reduced microbial transport following variable applications of beef cattle manure.*

Keywords. *Bacteria, Cattle manure,* E. coli*, Filter strips, Land application, Manure management, Manure runoff, Microbial, Microorganisms, Runoff.*

Microbial pathogens originating from beef cattle production facilities are a potential environmental concern (Khaleel et al., 1980; Swetten and Redell, 1978). Miner et al. (1966) and Young et al. (1980) found the concentration of fecal coliforms in runoff from feedlots to be 7.52 and 6.88 log CFU per 100 mL, respectively (table 1). An *E. coli* bacterial count in runoff from feedlot surfaces of 14.0 log CFU per 100 mL was measured by Gilley et al. (2008a, 2009).

The concentration of indicator organisms in runoff from grazed areas is influenced by livestock density, which is substantially smaller on grazed areas than feedlots. Doran et al. (1981), Edwards et al. (2000), Jawson et al. (1982), and Soupir et al. (2006) measured the concentration of fecal coliforms in runoff from grazed areas to be 5.06, 5.32, 3.18, and 5.22 log CFU per 100 mL, respectively (table 1). Little difference was found in bacterial concentrations in runoff between grazed areas and ungrazed control pastures. This similarity has been attributed to contamination of control areas by wild animals or the establishment of stable bacterial populations in the soil.

Manure from feedlots is often land-applied at rates required to meet crop nutrient requirements. Durso et al. (2011) and Thurston-Enriquez et al. (2005) determined *E. coli* transport in runoff from land application areas to be 12.63 and 12.70 log CFU per 100 mL, respectively (table 1). These values are over one order of magnitude less than the measurements of 14.0 log CFU per 100 mL obtained by Gilley et al. (2008a, 2009) for concentrations of *E. coli* in runoff from feedlots.

Vegetative filter strips (VFS) are recommended as a best management practice for reducing the transport of contaminants in runoff from land application areas. The ability of VFS to control pollution from feedlot runoff was investigated by Young et al. (1980). Mean concentrations of fecal coliforms entering and exiting an 18.3 m vegetated area were 6.88 and 6.54 log CFU per 100 mL, respectively (table 1). Lim et al. (1998) found that a 6.1 m filter strip reduced the concentration of fecal coliforms in runoff from an upslope area containing beef cattle manure from 7.30 to 0.00 log CFU per 100 mL. The plots containing tall fescue used by Lim et al. (1998) may have had a much larger water intake capacity than the recently established orchard grass plots used by Young et al. (1980).

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Table 1. Microbial concentrations in runoff from feedlots, grazed areas, land application sites, and vegetative filter strips.

Land Use and Reference	Total Coliforms (log CFU per 100 mL)	Fecal Coliforms (log CFU per 100 mL)	Fecal Streptococci (log CFU per 100 mL)	*E. coli* (log CFU per 100 mL)	Enterococci (log CFU per 100 mL)	Phages (log PFU per 100 mL)
Feedlots						
Gilley et al., 2008a	-	-	-	14.0	-	-
Gilley et al., 2009	-	-	-	14.0	-	-
Miner et al., 1966	7.90	7.52	7.38	-	-	-
Young et al. 1980	7.96	6.88	7.66	-	-	-
Grazed areas						
Doran et al., 1981	5.75	5.06	5.53	-	-	-
Edwards et al., 2000	-	5.32	-	-	-	-
Jawson et al., 1982	5.89	3.18	3.34	-	-	-
Soupir et al., 2006	-	5.22	-	5.14	5.08	-
Land application sites						
Durso et al., 2011	12.91	-	-	12.63	11.81	11.08
Thurston-Enriquez et al., 2005	-	-	-	12.70	12.13	-
Vegetative filter strips (entering/exiting the filter strip)						
Young et al., 1980	7.96/7.62	6.88/6.54	7.66/7.11	-	-	-
Lim et al., 1980	-	7.30/0.00	-	-	-	-

Edwards et al. (1996) developed an algorithm for VFS design for grassed areas treated with animal manures. The algorithm assumes that only infiltration is responsible for pollutant removal. Microbes transported in overland flow are suspended and not dissolved constituents. As a result, mechanisms other than infiltration and dilution may contribute to reductions in microbial transport within vegetative areas. Therefore, existing procedures for VFS design may need to be modified when considering microbial transport.

Placement of narrow grass hedges along the slope contour provides benefits similar to those of vegetative filter strips (Dewald et al., 1996; Eghball et al., 2000; Gilley et al., 2008b; Jin and Romkens, 2000; Kemper et al., 1992). Improved soil hydraulic properties beneath grass hedges help to enhance infiltration and reduce runoff (Rachman et al., 2004a, 2004b; Owino, 2006). Narrow grass hedges also promote sediment deposition and berm formation, and they diffuse and spread overland flow (Dabney et al., 1995, 1999; Meyer et al., 1995). Vegetation within grass hedges may reduce microbial release by providing a canopy to protect manure-borne microbes from dispersion during rainfall events and increase hydraulic resistance by overland flow (Blaustein et al., 2015; Cardoso et al., 2012). The objective of the present study was to determine the effectiveness of a narrow grass hedge in reducing microbial transport following variable applications of beef cattle manure.

Materials and Methods

Study Site Characteristics

Study site details are provided by Gilley et al. (2011). To summarize, this field study was conducted at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, Nebraska. The study site had been cropped using a rotation of sorghum [*Sorghum bicolor* (L.) Moench], soybean [*Glycine max* (L.) Merr.], and winter wheat [*Triticum aestivum* (L.) cv. Pastiche] under long-term no-till management with controlled wheel traffic. Manure had not been applied nor the area grazed since the 1960s. Sorghum was planted during the 2008 season, and soil on the site remained undisturbed following sorghum harvest. Herbicide (glyphosate) was used during the study as needed to control weed growth on the plot areas that were not covered by a grass hedge.

The Aksarben silty clay loam (fine, smectitic, mesic Typic Argiudoll) at the site developed in loess under prairie vegetation. Soil samples for study site characterization were obtained on each plot from the surface down to 2 cm just prior to manure application, and the soil samples were air-dried following collection. Mean measured concentrations of Bray and Kurtz No. 1 P, water-soluble P, NO_3-N, and NH_4-N were 49, 4.1, 18, and 5 mg kg^{-1}, respectively. The soil at the study site had a mean electrical conductivity (EC) of 0.47 dS m^{-1} and a pH of 7.2.

Plot Preparation

Twenty-four 0.75 m × 4 m plots were established with the 4 m plot dimension parallel to the slope in the direction of overland flow (fig. 1). Experimental treatments included the presence or absence within the plot of a 1.4 m wide switchgrass (*Panicum virgatum*) hedge and varying manure application rates. The existence or absence of a grass hedge was the main plot treatment, and manure application rate was the subplot treatment. Calculations of microbial transport per unit area included the section covered by the hedge.

Narrow grass hedges were established during 1998 in parallel rows following the contour of the land. A specialized grass drill was used in the seeding operation. The grass hedges were spaced at intervals along the hillslope that allowed multiple passes of tillage equipment. The narrow grass hedges were part of a strip-cropping system, and row crops were planted between the hedges.

The 1.4 m grass hedge examined in this study was located at the downslope portion of 12 of the plots (established using a randomized design) on which slope gradients averaged 3.7% (fig. 1). The other 12 plots (also established using a randomized design) had a mean slope gradient of 3.9%.

Field tests were conducted on six plots each week from 7 to 30 July 2009. Just prior to field application, manure from heifer calves was collected from feedlot pens located at the U.S. Meat Animal Research Center near Clay Center, Nebraska. Heifer calves born during the spring of 2008 were

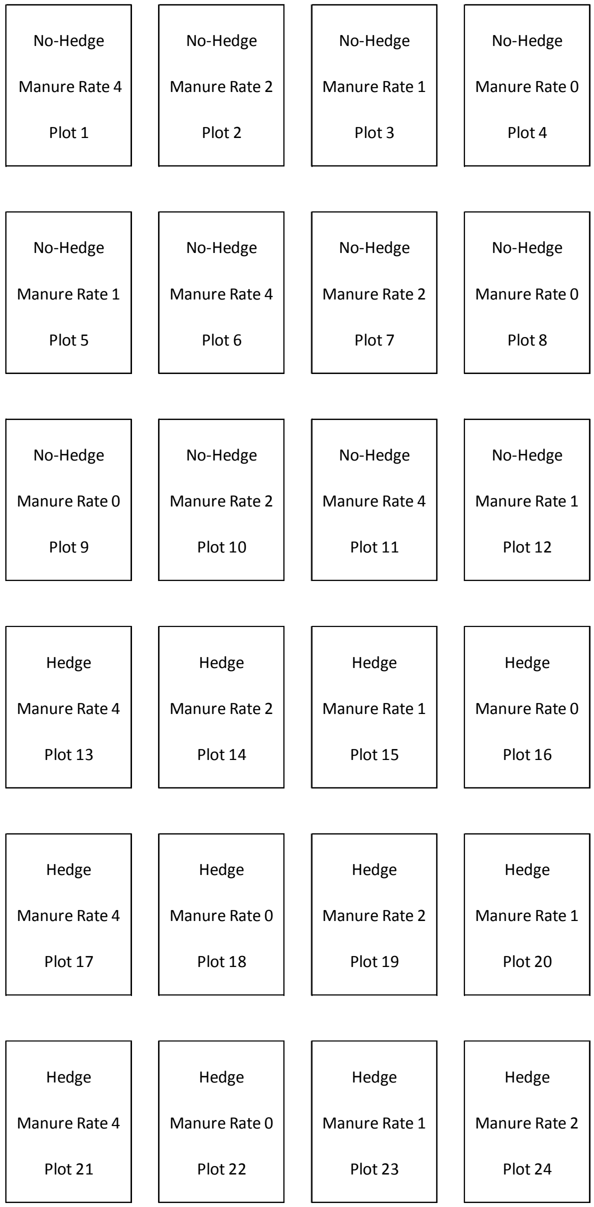

Figure 1. Schematic of plot layout, hedge and no-hedge treatments, and manure application rates. Grass hedge was 1.4 m, and total plot length was 4.0 m. Manure was applied in amounts required to meet none or the 1-, 2-, or 4-year nitrogen requirement for corn.

placed in the pens in September 2008 at a rate of 36 head per pen (50 m^2 per head).

The manure was carefully spread by hand over the application area using 19 L buckets. The entire 0.75 m × 4 m area on the no-hedge treatments (except the no-manure plots) received manure (fig. 1). However, manure was only applied to the 0.75 m × 2.6 m area above the 1.4 m grass hedge on the hedge treatments (except the no-manure plots). Thus, the upslope contributing area on the treatments containing a hedge was approximately 35% less than on the no-hedge treatments. This difference was addressed in the data interpretation.

The nutrient characteristics of the manure collected each week were measured, and manure application amounts were then calculated. Manure was applied in amounts required to meet none or the 1-, 2-, or 4-year nitrogen requirement for corn (151 kg N ha^{-1} $year^{-1}$ for an expected yield of 9.4 Mg ha^{-1}). When calculating manure application rates, it was assumed that the N availability from beef cattle manure was 40% of the total amount of nitrogen measured in the manure (Eghball et al., 2002). The 1-, 2-, and 4-year N application rates provided total P quantities of 92, 184, and 368 kg ha^{-1}. The amounts of NO_3-N, NH_4-N, total N, total P, water content, EC, and pH of the manure were 0.01 g kg^{-1}, 0.40 g kg^{-1}, 23 g kg^{-1}, 6.9 g kg^{-1}, 211 g kg^{-1}, 30 dS m^{-1}, and 8.3, respectively. The mean quantities of phages, total coliforms, *E. coli*, and enterococci contained in the manure immediately prior to application were 4.16 log PFU per 100 g, 8.46 log CFU per 100 g, 8.43 log CFU per 100 g, and 6.94 log CFU per 100 g, respectively.

RAINFALL SIMULATION PROCEDURES

Water used in the rainfall simulation tests was obtained from an irrigation well. The background phage and bacterial levels of the water from the irrigation well were tested. Mean concentrations of phages, total coliforms, *E. coli*, and enterococci were 0.00 log PFU per 100 mL, 2.90 log CFU per 100 mL, 2.02 log CFU per 100 mL, and 2.82 log CFU per 100 mL, respectively. Each of these concentrations was several orders of magnitude less than the value obtained in runoff. Thus, the manure, and not the water from the irrigation well, was the principal source of microbes.

Rainfall simulation procedures established by the National Phosphorus Research Project were used in this study (Sharpley and Kleinman, 2003). A portable rainfall simulator based on the design by Humphry et al. (2002) was used to apply rainfall to paired plots. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the plots. Water was first added to the plots with a hose until runoff began, providing more uniform antecedent soil water conditions. The simulator was then used to apply rainfall for 30 min at an intensity of 70 mm h^{-1}. Two additional rainfall simulation runs were conducted for the same duration and intensity at approximately 24 h intervals.

Plot borders channeled runoff into a sheet metal lip that emptied into a collection trough located across the downslope border of each plot. The trough diverted runoff into plastic buckets. A sump pump was then used to transfer runoff from the plastic buckets into larger plastic storage containers. The storage containers were weighed at the completion of each test to determine total runoff volume. Mean runoff amounts on the hedge and no-hedge treatments were 6.4 and 14.4 mm, respectively. Accumulated runoff was agitated to maintain suspension of solids. Runoff samples were then collected for microbial, water quality, and sediment analyses.

The microbial transport values presented in table 1 are not flow-weighted. The cumulative runoff from the entire rainfall event was collected in large plastic storage containers. A subsample of the runoff was then obtained from the storage containers, and microbial analyses were performed on the subsample.

SAMPLE ANALYSES

Somatic phages were assayed using the single-layer agar method (USEPA, 2001), resulting in counts of plaque forming units (PFU) that are displayed as individual clear lysis zones on a lawn of bacterial hosts. PFU counts represent the growth of a single virus, or a clump of virons that result in a single plaque.

Enumeration of total coliforms, *E. coli*, and enterococci was performed using the EPA-approved Quanti-Tray system (IDEXX Laboratories, Westbrook, Maine). For these microorganisms, 10 g of sample was combined with 90 mL of phosphate-buffered saline and manually mixed prior to inoculation. All samples were incubated for 24 h. *E. coli* and total coliform assays were incubated at 37°C, and enterococcus trays were maintained at 42°C (APHA, 2014).

Centrifuged and filtered runoff samples of a known volume were analyzed for dissolved P (DP) (Murphy and Riley, 1962), and NO_3-N and NH_4-N (measured with a flow injection analyzer using spectrophotometry; AutoAnalyzer 3, SEAL Analytical Ltd., Southampton, U.K.). Samples that were not centrifuged were analyzed for total phosphorus (TP) (Johnson and Ulrich, 1959), total nitrogen (TN) (Tate, 1994), pH, and electrical conductivity (EC) (Klute, 1986). Particulate phosphorus (PP) was obtained by subtracting DP measurements from TP values.

Statistical Analyses

Analysis of variance (SAS Mixed Procedure; SAS, 2003) was performed to determine the effects on microbial transport of the three experimental treatments: narrow grass hedge (yes or no), manure application rate (0-, 1-, 2-, or 4-year N requirement), and rainfall simulation run (1, 2, or 3). When conducting the analyses, it was assumed that the experimental data were normally distributed. The experimental treatments were replicated three times, so the number of observations for each of the variables was 72. If a significant difference was identified, the least significant difference (LSD) test was used to identify differences among experimental treatments. A probability level of <0.10 was considered significant. Microbial transport values varied by orders of magnitude among experimental treatments. Therefore, a less restrictive probability level of <0.10 rather than 0.05 was selected. Pearson correlation coefficients (SAS COOR Procedure) were used to identify the relationships between microbial transport and selected water quality characteristics. The number of observations for each of the variables was 72. A correlation coefficient was significant at the 95% level.

Results and Discussion

Microbial Transport as Affected by Hedge

The quantities of phages, *E. coli*, and enterococci transported in runoff were significantly less on the hedge treatments (table 2). The hedge reduced total counts of phages, *E. coli*, and enterococci from 10.8 to 9.01 log PFU ha^{-1}, from 12.4 to 11.9 log CFU ha^{-1}, and from 11.8 to 11.2 log CFU ha^{-1}, respectively. The 1.4 m wide grass hedge used in this study covered approximately 35% of the total 4 m plot length. As a result, microbial transport would be expected to be less with the narrow grass hedge in place because of the smaller upslope contributing area. However, the reduction in microbial loads in runoff from the plots with a grass hedge was larger than could be attributed simply to a smaller upslope contributing area. The potential contribution to total measured microbial transport provided by the grass hedge area was unknown.

The hedge by manure application rate interaction for total coliforms was found to be significant (table 2). The total coliform count of 12.7 log CFU ha^{-1} measured on the no-manure treatment for the plots containing a hedge was significantly less than the values of 13.1 and 13.3 log CFU ha^{-1} obtained for manure application rates providing 1-year and 2-year N requirements (fig. 2). No significant differences in total coliform measurements were found among the three manure application rates on the plots containing a hedge.

The total coliform count for no manure application on the plots with no hedge was 11.9 log CFU ha^{-1}, which was significantly less than the measurements obtained on plots where manure was applied (fig. 2). For the no-hedge treatment, the total coliform count of 13.0 log CFU ha^{-1} obtained for the 1-year N application rate was significantly less than

Table 2. Microbial transport as affected by hedge, manure application rate, and rainfall simulation run.[a]

Variable	Value	Phages (log PFU ha^{-1})	Total Coliforms (log CFU ha^{-1})	*E. coli* (log CFU ha^{-1})	Enterococci (log CFU ha^{-1})
Hedge	Hedge	9.01 b	13.0	11.9 b	11.2 b
	No hedge	10.8 a	13.0	12.4 a	11.8 a
	Standard error	0.379	0.124	0.185	0.193
Manure application rate	No manure applied	8.16 b	12.3 b	10.4 b	10.4 b
	1-year N requirement	9.92 a	13.1 a	12.6 a	11.7 a
	2-year N requirement	10.9 a	13.4 a	13.0 a	12.1 a
	4-year N requirement	10.6 a	13.3 a	12.6 a	11.8 a
	Standard error	0.463	0.176	0.262	0.273
Rainfall simulation run	1	8.91 b	12.7 b	11.8 b	11.2 b
	2	10.3 a	13.3 a	12.5 a	11.7 a
	3	10.5 a	13.1 a	12.2 a	11.6 a
	Standard error	0.324	0.123	0.154	0.154
ANOVA (Pr>F)	Hedge	0.03	0.79	0.04	0.06
	Manure rate	0.01	0.01	0.01	0.01
	Rainfall simulation run	0.01	0.01	0.01	0.01
	Hedge × manure rate	0.47	0.07	0.30	0.28
	Hedge × run	0.82	0.39	0.76	0.25
	Manure rate × run	0.94	0.49	0.09	0.23
	Manure rate × run × hedge	0.67	0.71	0.81	0.62

[a] Within a variable, values in the same column followed by different letters are significantly different at 0.10 probability level based on LSD test.

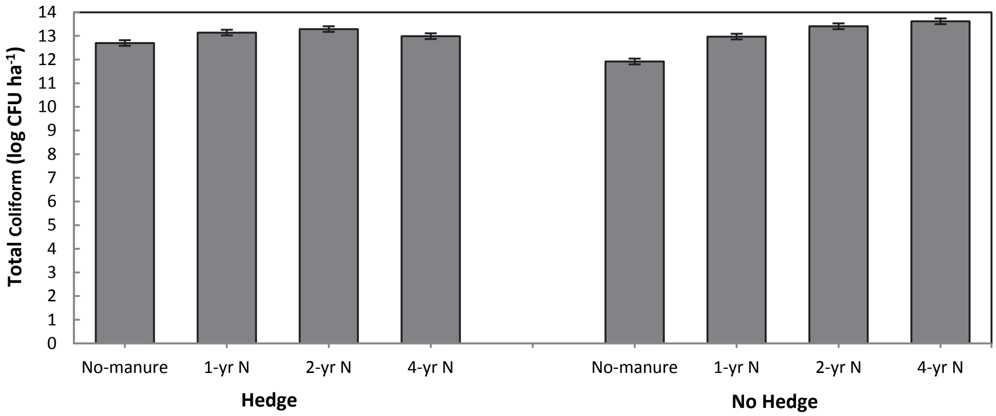

Figure 2. Total coliform transport as affected by manure application rate for the hedge and no-hedge conditions. Total coliform transport values are averages from three rainfall simulation runs. Vertical bars are standard errors.

the values of 13.4 and 13.6 log CFU ha^{-1} measured for the 2-year and 4-year manure application rates.

The load of manure-borne microorganisms in runoff following the application of beef cattle manure at a rate required to meet the annual N requirements for corn was measured by Thurston-Enriquez et al. (2005). Mean transport rates of *E. coli* and enterococci from the plots on which fresh cattle manure was applied were 12.7 and 12.1 log CFU ha^{-1}, respectively. In the present study, the transport rates for *E. coli* and enterococci on the control plots without a grass hedge were 12.4 and 11.8 CFU ha^{-1}, respectively. Thus, the transport rates of *E. coli* and enterococci reported by Thurston-Enriquez et al. (2005) and those measured in the present study for the no-hedge conditions were similar.

Microbial Transport as Affected by Manure Application Rate

The mean counts of phages and enterococci on the plots without manure of 8.16 log PFU ha^{-1} and 10.4 log CFU ha^{-1} were significantly less than values obtained on the plots with manure, which varied from 9.92 to 10.9 log PFU ha^{-1} and from 11.7 to 12.1 log CFU ha^{-1} (table 2). For the plots that received manure, no significant differences in transport of phages or enterococci were found among the three manure application rates.

A significant manure application rate by rainfall simulation run interaction was found for *E. coli* (table 2). *E. coli* counts for the no-manure treatment were significantly less than measurements obtained on the plots that received manure (fig. 3). For the plots that received manure, *E. coli* counts were significantly less for the first rainfall simulation run than for the second run.

The effects of animal diet, manure application rate, and tillage on the transport of selected microorganisms from plots amended with beef cattle manure were measured by Durso et al. (2011). Transport rates for phages, total coliforms, *E. coli*, and enterococci were found to increase significantly from 10.4 to 11.2 log PFU ha^{-1}, from 12.7 to 13.2 log CFU ha^{-1}, from 12.3 to 13.0 log CFU ha^{-1}, and from 11.5 to 12.0 log CFU ha^{-1} as the manure application rate increased from a 1-year to a 4-year P requirement for corn. The manure application rates applied by Durso et al. (2011) were less than those used in the present study. The quantity of beef cattle manure needed to meet a 4-year P requirement for corn is approximately equal to a 1-year N requirement. The larger quantity of manure applied in the present study may have resulted in similar transport rates of phages and enterococci among the three manure application rates.

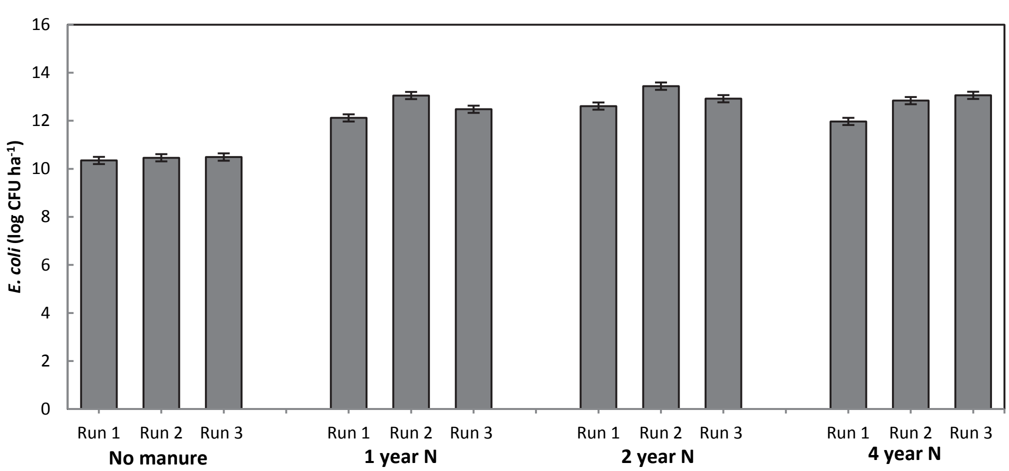

Figure 3. *E. coli* transport as affected by rainfall simulation run and manure application rate. *E. coli* transport values are averages from three rainfall simulation runs. Vertical bars are standard errors.

MICROBIAL TRANSPORT AS AFFECTED BY RAINFALL SIMULATION RUN

Rainfall simulation run significantly affected measurements of phages, total coliforms, and enterococci, with measurements during the three runs varying from 8.91 to 10.5 log PFU ha^{-1}, from 12.7 to 13.3 log CFU ha^{-1}, and from 11.2 to 11.7 log CFU ha^{-1}, respectively (table 2). Counts for phages, total coliforms, and enterococci were significantly less for the first rainfall simulation run than for the second and third runs. No significant differences in transport values for phages, total coliforms, and enterococci were found between the second and third rainfall simulation runs.

The load of manure-borne microorganisms in runoff following the application of beef cattle manure at a rate required to meet the annual N requirements for corn was measured by Thurston-Enriquez et al. (2005). Transport rates for *E. coli* and enterococci increased from 10.8 to 13.0 CFU ha^{-1} and from 11.5 to 12.2 CFU ha^{-1}, respectively, between the first and second rainfall simulation runs. In the present study, the loads of *E. coli* and enterococci increased significantly from 11.8 to 12.5 CFU ha^{-1} and from 11.2 to 11.7 CFU ha^{-1}, respectively, between the first and second rainfall simulation runs.

CORRELATION BETWEEN MICROBIAL TRANSPORT AND RUNOFF CHARACTERISTICS

Microbial transport (log PFU ha^{-1} or CFU ha^{-1}) was correlated to nutrient loads (kg ha^{-1}), measurements of EC (dS m^{-1}), and pH (table 3). All four of the microbial constituents were significantly correlated to DP, PP, TP, and TN loads. *E. coli* and enterococci counts were also significantly correlated to NH_4-N and EC. In addition, total coliforms and enterococci were significantly correlated to pH. Phosphorus concentrations were previously found to influence the survival of *E. coli* in drinking water (Juhna et al. 2007).

COMPARISON OF MICROBIAL TRANSPORT RATES WITH VALUES REPORTED PREVIOUSLY

Durso et al. (2011) applied beef cattle manure under till and no-till conditions to 0.75 m wide × 2 m long plots to meet the 1-, 2-, or 4-year phosphorus requirements for corn. Mean transport rates of phages, total coliforms, *E. coli*, and enterococci were 11.1 log PFU ha^{-1}, 12.9 log CFU ha^{-1}, 12.6 log CFU ha^{-1}, and 11.8 log CFU ha^{-1}, respectively. In the present study, beef cattle manure was applied to 0.75 m × 4.0 m long plots to meet the 1-, 2-, or 4-year N requirements for corn. Mean transport rates of 10.8 log PFU ha^{-1}, 13.0 log CFU ha^{-1}, 12.4 log CFU ha^{-1}, and 11.8 log CFU ha^{-1} were measured for phages, total coliforms, *E. coli*, and enterococci, respectively, on the plots with no hedge. Thus, the microbial transport measurements obtained in the present study were similar to values reported by Durso et al. (2011).

NARROW GRASS HEDGES AS A BEST MANAGEMENT PRACTICE

Manure can be used to meet annual or multi-year crop nutrient requirements. Land application costs can be reduced if manure can be applied at less frequent intervals. The use of narrow grass hedges planted along the contour was shown in the present study to significantly reduce microbial transport on a cropland area that received multi-year applications of manure.

The effectiveness of a single grass hedge in reducing microbial transport was examined in this study. Several narrow grass hedges are usually planted along the contour from near the top to the bottom of a hillslope. Thus, several narrow grass hedges may intercept overland flow moving downslope and be even more effective in reducing microbial transport than the single hedge analyzed in this study.

The use of narrow grass hedges is only one of several best management practices available for reducing microbial transport in runoff. The presence of a grass hedge system should not be viewed as an opportunity to apply manure at excessive rates. Narrow grass hedges are best used as one part of a combination of several best management practices.

Planning and placement of narrow grass hedges, allowing the grass hedges to mature, and managing the hedges represent a substantial investment. The reduction in microbial transport provided by grass hedges may be statistically significant but was less than one log scale in the present study. Other benefits, such as reductions in sediment and nutrient content, may need to be considered to justify use of grass hedges as a best management practice on cropland areas.

CONCLUSIONS

A narrow grass hedge significantly reduced total counts of phages, *E. coli*, and enterococci in runoff. For the plots that received manure, no significant differences in transport of phages or enterococci were found among the three manure application rates. Measurements of phages, total coliforms, and enterococci varied significantly among the three rainfall simulation runs.

The microbial transport measurements obtained in this study were for conditions occurring soon after the addition of manure without incorporation and the application of rainfall at a relatively high intensity. Therefore, the experimental results represent an extreme condition. Microbial transport

Table 3. Correlation coefficients of microbial transport with water quality characteristics.[a]

Microbial Constituent	DP	PP	TP	NH_4-N	TN	NO_3-N	EC	pH
Phages	0.40	0.44	0.41	0.23	0.31	0.15	0.23	-0.04
	(0.01)	(0.01)	(0.01)	(0.06)	(0.01)	(0.21)	(0.06)	(0.70)
Total coliforms	0.31	0.35	0.32	0.15	0.25	-0.18	0.10	-0.29
	(0.01)	(0.01)	(0.01)	(0.20)	(0.03)	(0.13)	(0.40)	(0.01)
E. coli	0.42	0.46	0.43	0.28	0.35	-0.04	0.28	-0.18
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.75)	(0.02)	(0.14)
Enterococci	0.42	0.46	0.43	0.25	0.34	0.01	0.23	-0.23
	(0.01)	(0.01)	(0.01)	(0.04)	(0.01)	(0.97)	(0.04)	(0.04)

[a] DP = dissolved phosphorus, PP = particulate phosphorus, TP = total phosphorus, TN = total nitrogen, and EC = electrical conductivity. Values in parentheses represent Pr>|r|. A correlation coefficient is significant at the 95% level if |correlation| > 0.23 for n = 72.

values would be expected to decrease over time following manure application.

Microbial transport loads will be different at other locations with varying soil and vegetative characteristics. The measurements reported in this study were influenced by the slope length, steepness, cropping, vegetative, and management conditions used in this study. For the given experimental conditions, narrow grass hedges significantly reduced microbial transport in runoff occurring soon after manure application.

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