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WHEAT STRIP EFFECTS ON MICROBIAL TRANSPORT FOLLOWING VARIABLE APPLICATIONS OF BEEF CATTLE MANURE

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ABSTRACT. *Vegetative filter strips (VFS) consisting of perennial vegetation have been successfully used to reduce the transport of contaminants in runoff from land application areas. The effectiveness of a winter wheat strip, which may be more acceptable to producers, in reducing microbial transport was examined in this study. A 1.4 m wheat strip was used to allow direct comparison with experimental results obtained in previous studies. 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 the 0- 1-, 2-, or 4-year phosphorus requirement for corn. The transport of selected microbes was measured for three 30 min simulated rainfall events separated by 24 h intervals. The narrow wheat strip did not significantly reduce counts of any of the measured microbes. The application of manure to meet the 4-year P requirement resulted in* E. coli *and enterococci loads that were significantly greater than the 1-year P requirement. Rainfall simulation run significantly affected measurements of phages, total coliforms,* E. coli*, and enterococci, with measurements during the three runs varying from 9.35 to 10.9 log plaque-forming units (PFU) ha^{-1}, from 11.5 to 12.1 log colony-forming units (CFU) ha^{-1}, from 12.1 to 12.5 log CFU ha^{-1}, and from 11.1 to 11.4 log CFU ha^{-1}, respectively. The transport of* E. coli *was found to be significantly correlated to selected nutrient loads and electrical conductivity of runoff. The presence of narrow wheat strips did not reduce microbial loads in runoff.*

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 transport 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).

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) measured *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 log scale less than measurements obtained by Gilley et al. (2008a, 2009).

Vegetative filter strips (VFS) are located between a pollutant-source area and a water source such as a stream, lake, or pond. Contaminants in runoff from areas containing pollutants have been substantially reduced by VFS. The ability of VFS to control microbial transport 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 study site 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).

VFS should not be confused with a vegetative treatment system (VTS) used for treating runoff from an animal feeding operation. A VTS uses a sediment basin to remove solids from a feedlot and employs controlled release of the liquids in runoff to a vegetated treatment area (VTA). The VTA uses the water-holding capacity of the soil to store runoff until the water and nutrients can be used by perennial vegetation.

Narrow wheat strips could potentially be used to serve the same function as VFS. The extensive root system provided

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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	-	-	-
Jawson et al., 1982	5.89	3.18	3.34	-	-	-
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., 1998	-	7.30/0.00	-	-	-	-

by winter wheat could reduce erosion by helping to hold soil in place. The relatively dense vegetation provided by wheat strips could also reduce overland flow velocity, which in turn would decrease sediment transport capacity (Tollner et al., 1976, 1977). The small ponded area occurring upslope of a wheat strip may also cause deposition. The incorporation of wheat strips as part of a strip cropping practice has been shown to effectively reduce soil loss from cropland areas (Gilley et al., 1997).

Farmers may be more willing to incorporate an annual crop like winter wheat into their management system than to remove part of their field from crop production, as is required when VFS are established. Little information is currently available concerning the suitability of narrow wheat strips in reducing microbial transport by overland flow. The objective of the present study was to determine the effectiveness of a narrow wheat strip in reducing microbial transport following the application of varying rates of beef cattle manure.

Materials and Methods

Study Site Characteristics

Field tests were conducted in May and June 2010 at the University of Nebraska Roger's Memorial Farm located 18 km east of Lincoln, Nebraska, in Lancaster County (40° 5′ N, 96° 3′ W). Additional details concerning the experimental study are provided by Thayer et al. (2012). Soils at the study location were derived from loess deposits with prairie vegetation, and the site had a mean slope of 4.8%. The top 2 cm of the Aksarben silt loam soil (fine, smectitic, mesic Typic Argiudoll) contained 17% sand, 58% silt, 25% clay (Kettler et al., 2001), 5.3% organic matter, and 3.1% total carbon (Nelson and Sommers, 1996). The soil had an electrical conductivity of 0.31 dS m^{-1}, a pH of 7.6 (Klute, 1986), and concentrations of Bray and Kurtz No. 1 phosphorus (P) (Bray and Kurtz, 1945), water-soluble P (Murphy and Riley, 1962), and NO_3-N, and NH_4-N measured with a flow injection analyzer using spectrophotometry (AutoAnalyzer 3, SEAL Analytic Inc., Mequon, Wisc.) of 37.4, 2.7, 5.7, and 11.0 mg kg^{-1}, respectively. The study location had been cropped under a no-till management system using a rotation of grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), and winter wheat (*Triticum aestivum* L. cv. Pastiche). Soybeans were harvested from the site before it was planted to winter wheat, and herbicide was applied as needed to control weed growth.

Plot Preparation

Twenty-four 0.75 m wide by 4.0 m long plots were used in this study, with the longer plot dimension parallel to the slope in the direction of overland flow (fig. 1). Experimental treatments included the presence or absence of a 1.4 m long wheat strip (fig. 2) and manure application rates of 0, 9.2, 18.4, or 36.8 Mg ha^{-1} (obtained on a dry weight basis), which met the 0-, 1-, 2-, or 4-year P requirements for corn (25.8 kg P ha^{-1} for an expected annual yield of 9.4 Mg ha^{-1}). Each of the experimental treatments was replicated three times.

The field site was planted to winter wheat on September 30, 2009, in a direction perpendicular to overland flow. A drill with 19 cm row spacing was used to seed the winter wheat at a target population of 3.0 million seeds per hectare. Soybean residue from previous crops was also present on the soil surface at the time of the study. Twenty-four plots were established across the slope using a completely randomized experimental design. Twelve non-contiguous plots identified from the randomized design (no wheat strip) were sprayed with a non-selective herbicide in March 2010 to kill the existing wheat plants. Substantial vegetative growth was present when the herbicide was applied. The same non-selective herbicide was also applied to the other 12 non-contiguous wheat strip plots identified from the randomized design, except for a 1.4 m long strip located on the downslope portion of the plots on which winter wheat continued to grow (fig. 2). Field tests had been conducted before by Gilley et al. (2008b, 2011) using 1.4 m long switchgrass (*Panicum virgatum*) hedges planted on a nearby site at the Roger's Memorial Farm. Therefore, a 1.4 m long winter wheat strip was used in this investigation to allow comparisons of experimental results with measurements obtained in the previous studies.

Beef cattle manure from calves fed a corn-based diet was collected from feedlot pens located at the U.S. Meat Animal Research Center near Clay Center, Nebraska. Concentrations of NO_3-N and NH_4-N (measured with a SEAL Auto

Figure 1. Schematic of plot layout, wheat strip and no wheat strip treatments, and manure application rates. The wheat hedge was 1.4 m long, and total plot length was 4.0 m. Manure was applied in amounts required to meet the 0-, 1-, 2-, or 4-year P requirements for corn.

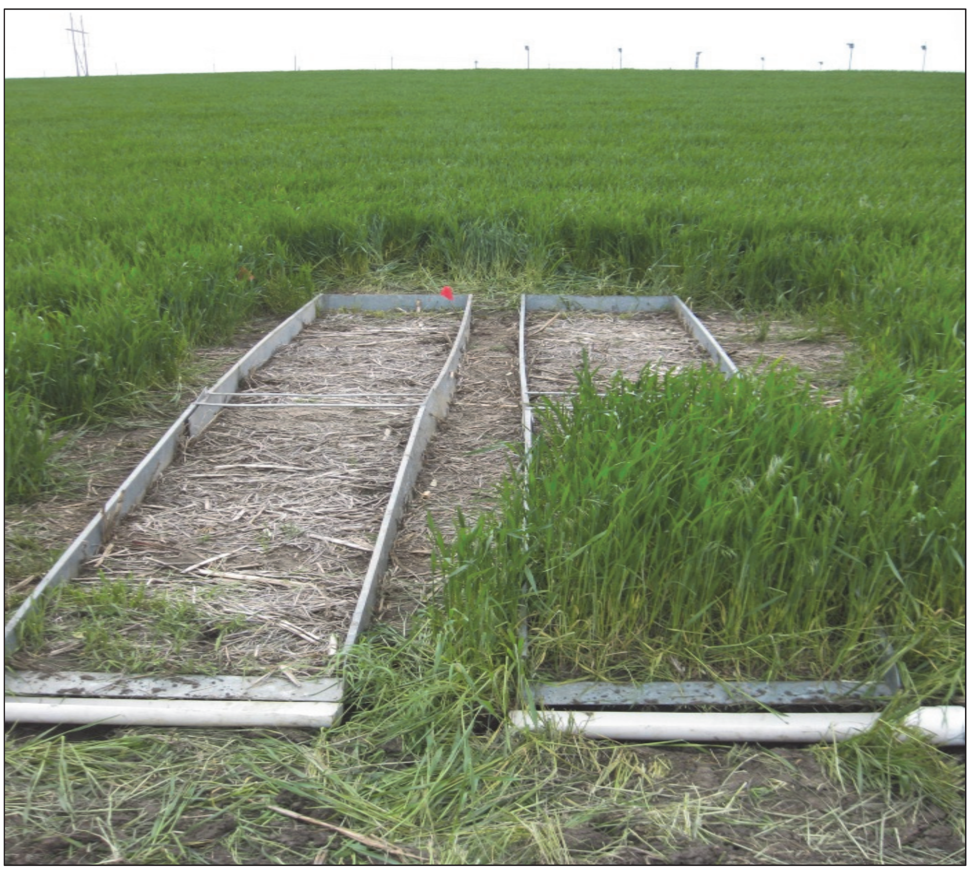

Figure 2. Paired experimental plots including a no wheat strip treatment and 1.4 m wheat strip on the downslope portion of a 4.0 m plot. Runoff collection troughs are shown at the bottom of each of the plots.

Analyzer 3 flow injection analyzer using spectrophotometry), total N (Bremner and Mulvaney, 1982), total P (TP) (Olsen and Sommers, 1982), water content (Gardner, 1982), electrical conductivity, and pH of the manure were 0.01 g kg^{-1}, 0.15 g kg^{-1}, 11 g kg^{-1}, 3.3 g kg^{-1}, 70 g kg^{-1}, 12 dS m^{-1}, and 8.4, respectively.

Rainfall simulation tests were conducted on six plots each week using established data collection protocols. The microbial characteristics of manure can change over time, especially following precipitation events. Therefore, manure was only applied without incorporation each week to the six plots on which rainfall simulation tests were to be conducted.

The application of beef cattle manure under no-till or minimal-till conditions occurs frequently in this region. However, additional management considerations are required when manure is broadcast without incorporation. The availability of nutrients to the crop over the growing season and soil nutrient stratification must be addressed. Increased weed competition and odors may be present when manure is applied under no-till and minimum-till conditions. The potential for off-site transport of contaminants is increased when manure is not incorporated. Therefore, the microbial loads reported in this study immediately following the broadcast application of manure are larger than would be expected if the manure had been incorporated.

A single application of beef cattle manure was carefully spread by hand over the treatment area immediately before the weekly rainfall simulation tests using 19 L buckets. The entire 0.75 m × 4 m area on the no wheat strip treatment (except the no-manure plots) received manure (fig. 2). However, manure was only applied to the 0.75 m × 2.6 m area above the 1.4 m wheat strip on the treatments containing wheat strips (except the no-manure plots). Therefore, the upslope contributing area on the treatments containing a wheat strip was approximately 35% less on the treatments with no wheat strip. This difference in contributing area was addressed in the data interpretation.

When calculating manure application rates, it was assumed that nitrogen (N) and P availability from beef cattle manure were 40% and 85%, respectively (Eghball et al., 2002). Supplemental urea ($(NH_2)_2CO$) fertilizer N (39-0-0, N-P-K) was added at rates required to meet annual N crop growth requirements for corn (151 kg N ha^{-1} for an expected yield of 9.4 Mg ha^{-1}). Application of manure to meet the 4-year corn P requirement provided 160 kg ha^{-1} of total N, which was slightly larger than the 151 kg ha^{-1} annual N requirement. The mean quantities of phages, total coliforms, *E. coli*, and enterococci contained in the manure were 4.27 log plaque-forming units (PFU) per 100 g, 6.41 log colony-forming units (CFU) per 100 g, 6.53 log CFU per 100 g, and 5.51 log CFU per 100 g, respectively.

Rainfall Simulation Procedures

Water used in the rainfall simulation tests was obtained from an irrigation well. Water from the irrigation well contained mean concentrations of phages, total coliforms, *E. coli*, and enterococci of 0.00 log PFU per 100 mL, 2.88 log CFU per 100 mL, 1.91 log CFU per 100 mL, and 2.62 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.

Measured mean concentrations of dissolved P (DP) (Murphy and Riley, 1962), TP (Johnson and Ulrich, 1959), NO_3-N, and NH_4-N (measured with a SEAL AutoAnalyzer 3 flow injection analyzer using spectrophotometry), and total N (Tate, 1994) in the irrigation water were 0.17, 0.17, 14.9, 0.00, and 14.9 mg L^{-1}, respectively. The irrigation water had an electrical conductivity of 0.79 dS m^{-1} and a pH of 7.4.

Rainfall simulation procedures adopted by the National Phosphorus Research Project (Sharpley and Kleinman, 2003) were employed in this study, which occurred from May 25 to June 19, 2010. 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 70 mm h^{-1}. A storm in this area with this intensity and duration has a recurrence interval of approximately four years (NOAA, 2013). Two additional rainfall simulation tests were conducted for the same duration and intensity at approximately 24 h intervals. A three-day storm producing 105 mm of rainfall in this area has a recurrence interval of approximately three years. Four rain gauges were placed along the outer edge of each plot, and two rain gauges were located between the plots. The area disturbed by placement of the sheet metal borders around the perimeter of the plot was relatively small, thus reducing the potential for preferential infiltration.

Multiple rainfall simulation runs are typically conducted on individual plots to help replicate the effects of wetting and drying cycles on runoff conditions. As an example, soils with significant amounts of clay particles may expand substantially under wet conditions. The additional data obtained during subsequent rainfall simulation tests are also important in identifying statistical differences among experimental treatments.

Water was slowly added to the plots using a garden hose with an adjustable nozzle until runoff was observed. The addition of water before the rainfall simulation tests helped to provide more uniform antecedent soil water conditions among the experimental treatments. Under actual field conditions, antecedent soil water content can vary substantially depending on the time of year and previous precipitation.

Plot borders channeled runoff into a sheet metal lip that emptied into a collection trough located across the bottom of each plot that 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 volume. Accumulated runoff was agitated to maintain suspension of solids, and a sample for microbial analyses was obtained.

Sample Analyses

Somatic phages were assayed using the single-layer agar method (USEPA, 2001), resulting in counts of 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 assays, 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. The *E. coli* and total coliform assays were incubated at 37°C, and the enterococcus trays were maintained at 42°C (APHA, 2014).

Centrifuged and filtered runoff samples of a known volume were analyzed for DP (Murphy and Riley, 1962), and NO_3-N and NH_4-N (measured with a SEAL AutoAnalyzer 3 flow injection analyzer using spectrophotometry). Samples that were not centrifuged were analyzed for 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 of the three experimental treatments: narrow wheat strip (yes or no), manure application rate (0-, 1-, 2-, or 4-year P requirement), and rainfall simulation run (1, 2, or 3) on microbial transport. The experimental treatments were replicated three times, so the number of observations for each of the variables was 72. A log-transform of the response variables (phages, total coliforms, *E coli*, and enterococci) was performed to satisfy statistical assumptions. If a significant difference was identified, the t-test was used to identify differences among experimental treatments. A probability level of <0.05 was considered significant. When conducting the t-test, it was assumed that all conditions for inference were met. Pearson correlation coefficients (SAS COOR Procedure) were used to identify the relationship between microbial transport and selected water quality characteristics. Correlation analyses was performed on log-transformed microbial data. 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 Wheat Strip

No significant differences were found in the quantities of phages, total coliforms, *E. coli*, and enterococci that were transported in runoff between the plots with and without wheat strips (table 2). 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 loads of *E. coli* and enterococci from the 0.75 m × 2 m plots on which fresh cattle manure was applied were 12.7 and 12.1 log CFU ha^{-1}, respectively. These values represent mean measurements from three consecutive 30 min simulated rainfall events, producing 35 mm of rainfall and separated by 24 h. In the present study, the transport rates for *E. coli* and enterococci on the plots where beef cattle manure was applied were 12.8 and 11.4 log CFU ha^{-1}, respectively.

Microbial Transport as Affected by Manure Application Rate

The mean counts of phages, *E. coli*, and enterococci on the plots without manure of 9.06 log PFU ha^{-1}, 10.5 log CFU ha^{-1}, and 11.0 log CFU ha^{-1}, respectively, were significantly less than the values obtained on the plots with manure, which varied from 10.5 to 11.1 log PFU ha^{-1}, from 12.5 to 13.0 log CFU ha^{-1}, and from 11.3 to 11.5 log CFU ha^{-1}, respectively (table 1). For the plots that received manure, no significant differences in the transport of phages were found among the three manure application rates. However, the application of manure to meet the 4-year P requirement resulted in *E. coli* and enterococci loads that were significantly greater than the 1-year P requirement.

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). Although the differences among individual manure application rates may not have been statistically

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

Variable		Phages (log PFU ha^{-1})	Total Coliforms (log CFU ha^{-1})	*E. coli* (log CFU ha^{-1})	Enterococci (log CFU ha^{-1})
Wheat strip	Wheat strip	10.2	11.8	12.1	11.3
	No wheat strip	10.6	11.3	12.3	11.2
	Standard error	0.147	0.984	0.111	0.072
Manure application rate[b]	No manure applied	9.06 b	10.8	10.5 c	11.0 c
	1-year P requirement	10.5 a	11.8	12.5 b	11.3 b
	2-year P requirement	10.9 a	11.4	12.9 ab	11.3 b
	4-year P requirement	11.1 a	12.4	13.0 a	11.5 a
	Standard error	0.208	1.06	0.152	0.101
Rainfall simulation run[c]	First rainfall event	9.35 b	11.5 ab	12.1 b	11.1 b
	Second rainfall event	10.9 a	12.1 a	12.5 a	11.4 a
	Third rainfall event	10.9 a	11.2 b	12.1 b	11.3 a
	Standard error	0.150	0.958	0.121	0.074
ANOVA (Pr > F)	Wheat strip	0.08	0.39	0.15	0.66
	Manure rate	0.01	0.25	0.01	0.01
	Rainfall simulation run	0.01	0.03	0.02	0.01
	Wheat strip × Manure rate	0.84	0.36	0.53	0.49
	Wheat strip × Run	0.55	0.50	0.45	0.11
	Manure rate × Run	0.22	0.70	0.90	0.96
	Manure rate × Run × Wheat strip	0.30	0.50	0.12	0.96

[a] Values followed by different letters are significantly different at the 0.05 probability level based on t-tests.
[b] Beef cattle manure was applied at rates required to meet the 0-, 1-, 2-, or 4-year annual P requirement for corn.
[c] Rainfall was applied for 30 min at an intensity of 70 mm h^{-1} during three rainfall events separated by 24 h intervals.

significant, transport rates for phages, *E. coli*, and enterococci increased from 10.4 to 11.2 log PFU ha^{-1}, from 12.3 to 13.0 log CFU ha^{-1}, and from 11.5 to 12.0 log CFU ha^{-1}, respectively, as manure application rate increased from a 1-year to a 4-year P application requirement for corn. Therefore, the microbial transport rates reported by Durso et al. (2011) and those obtained in the present study were similar.

In the present investigation, microbial transport on the plots where manure was not applied was relatively large (table 1). The transport of microbes in runoff from grazed and non-grazed watersheds has been reported in previous field studies to be similar. Doran et al. (1981) measured the bacteriological quality of runoff from a pasture grazed by beef cattle and a non-grazed control pasture in south central Nebraska from 1976 to 1978. For rainfall events, mean counts of total coliforms, fecal coliforms, and fecal streptococci from the grazed pasture were 5.75, 5.06, and 5.53 log CFU per 100 mL, respectively, compared to 5.65, 4.12, and 6.01 log CFU per 100 mL from the non-grazed pasture. The relatively large bacteriological counts from the non-grazed pasture were attributed to wildlife activity, including field mice and rabbits.

Total coliforms, fecal coliforms, and fecal streptococci in runoff from grazed and non-grazed watersheds in the Pacific Northwest were monitored by Jawson et al. (1982). Mean annual weighted-average counts of total coliforms, fecal coliforms, and fecal streptococci from the grazed pasture during the 1978 water year were 5.89, 3.18, and 3.34 log CFU per 100 mL, respectively, compared to 5.04, 1.81, and 3.40 log CFU per 100 mL from the non-grazed watershed (table 1). The presence of wildlife on the field site used in the present investigation may have contributed to the relatively large microbial transport values obtained on plots where manure was not applied, as occurred in the studies reported by Doran et al. (1981) and Jawson et al. (1982).

MICROBIAL TRANSPORT AS AFFECTED BY RAINFALL SIMULATION RUN

The rainfall simulation protocols used in the present study called for three 30 min rainfall simulation events separated by 24 h intervals. Rainfall simulation run significantly affected measurements of phages, total coliforms, *E. coli*, and enterococci, with values during the three runs varying from 9.35 to 10.9 log PFU ha^{-1}, from 11.5 to 12.1 log CFU ha^{-1}, from 12.1 to 12.5 log CFU ha^{-1}, and from 11.1 to 11.4 log CFU ha^{-1}, respectively (table 1). Counts for phages, *E. coli*, and enterococci were significantly less for the first rainfall simulation run than for the second run. Total runoff amounts for each of the simulation events were similar. No significant differences in transport values for phages 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 log CFU ha^{-1} and from 11.5 to 12.2 log CFU ha^{-1}, respectively, between the first and second rainfall simulation runs. A similar trend of an increase in microbial transport after the initial rainfall simulation run was found in the present investigation.

CORRELATION BETWEEN MICROBIAL TRANSPORT AND RUNOFF CHARACTERISTICS

Determination of microbial populations in runoff is labor-intensive, time-consuming, and expensive. If more easily measured surrogates for microbial transport could be identified, information on the potential presence of pathogens in surface waters could be more readily available. Therefore, the microbial transport (log PFU ha^{-1} or log CFU ha^{-1}) values obtained in this investigation were correlated to selected nutrient loads (kg ha^{-1}) and measurements of electrical conductivity (dS m^{-1}) and pH (table 3).

The transport of phages was significantly correlated to NH_4-N loads and pH. Total coliforms transport was negatively correlated to pH. Enterococci transport was not significantly correlated to any of the measured water quality constituents. The transport of *E. coli* was significantly correlated to dissolved P, particulate P, total P, NH_4-N, total N load, and electrical conductivity. Phosphorus concentrations were found previously to influence the survival of *E. coli* in drinking water (Juhna et al., 2007), which indicates there may be a correlation between bacterial populations and phosphorus concentrations.

COMPARISON OF MICROBIAL TRANSPORT RATES WITH VALUES REPORTED PREVIOUSLY

Durso et al. (2011) examined the effects of animal diet (corn or distiller's grain), manure application rate (1-, 2-, or 4-year corn P requirement), and tillage (till or no-till) on the transport of microorganisms from manure-amended fields. A grain sorghum-soybean-winter wheat crop rotation under no-till management was used at the study site, and the soil surface contained sorghum residue from the previous year. Mean transport rates of phages, total coliforms, *E. coli*, and enterococci for the plots on which manure from cattle fed a corn diet was applied were 10.2 log PFU ha^{-1}, 13.0 log CFU ha^{-1}, 13.0 log CFU ha^{-1}, and 11.9 log CFU ha^{-1}, respectively. In the present investigation, manure from beef cattle fed a

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

	DP	PP	TP	NH_4-N	TN	NO_3-N	EC	pH
Phages	0.09 (0.45)	0.05 (0.67)	0.07 (0.53)	**0.32** **(0.01)**	0.05 (0.66)	-0.12 (0.33)	-0.01 (0.94)	**0.42** **(0.01)**
Total coliforms	-0.01 (0.93)	0.07 (0.55)	0.03 (0.79)	0.03 (0.80)	-0.02 (0.88)	0.21 (0.08)	-0.02 (0.85)	**-0.27** **(0.02)**
E. coli	**0.44** **(0.01)**	**0.28** **(0.02)**	**0.39** **(0.01)**	**0.46** **(0.01)**	**0.27** **(0.02)**	-0.01 (0.91)	**0.36** **(0.01)**	0.05 (0.68)
Enterococci	0.13 (0.28)	0.15 (0.20)	0.15 (0.21)	0.15 (0.20)	-0.01 (0.97)	-0.11 (0.36)	-0.06 (0.59)	0.07 (0.58)

[a] Value in parentheses represent Pr > |r|. Correlation coefficients are significant at the 95% level (shown in **bold**) if |correlation| > 0.23 for n = 72. DP = dissolved phosphorus, PP = particulate phosphorus, TP = total phosphorus, TN = total nitrogen, and EC = electrical conductivity.

corn diet was also applied to 0.75 wide × 2.0 m long plots at rates required to meet the 1-, 2-, or 4-year P requirements for corn. Mean transport rates of 10.6 log PFU ha^{-1}, 11.3 log CFU ha^{-1}, 12.3 log CFU ha^{-1}, and 11.2 log CFU ha^{-1} were measured in the present study for phages, total coliforms, *E. coli*, and enterococci, respectively, on the plots with no wheat strip.

Gilley et al. (2008a, 2009) determined the mean transport of *E. coli* from feedlot surfaces to be 14.0 log CFU ha^{-1}. When the beef cattle manure was land-applied, the transport rate for *E. coli* was reduced to 12.6 log CFU ha^{-1} (Gilley et al., 2011). In the present study, *E. coli* transport for the no wheat strip treatment was 12.3 log CFU ha^{-1}. Thus, the *E. coli* transport values obtained in the present study appear to be consistent with previously reported field measurements.

Narrow Wheat Strips as a Best Management Practice

VFS have been shown to be an effective best management practice because of the dilution effects caused by infiltration of dissolved constituents in runoff and the input of rainfall within the VFS area. Microbes are suspended in overland flow and are not dissolved constituents. In contrast to VFS, as water infiltrates within a wheat strip, the concentration of suspended materials may increase rather than decrease because of the reduction in overland flow volume. However, the increase in suspended materials due to infiltration may be offset by the dilution effect of rainfall occurring over the wheat strip area.

The winter wheat strips examined in this investigation were planted on September 30, 2009, and the rainfall simulation tests were performed from May 25 to June 17, 2010, while the wheat plants were actively growing. Crop residue materials on the soil surface during the field tests consisted primarily of soybean residue remaining from the previous cropping season. It was not apparent at the stage of winter wheat development examined in this investigation that substantial deposition of sediment occurred immediately upslope of or within the wheat strip.

Suspended materials may be removed from runoff through the filtering action that occurs as overland flow moves through a relatively dense cover of surface residue materials. Removal of suspended materials works best when the height of surface residue elements is greater than the overland flow depth. The effectiveness of winter wheat residue in filtering suspended materials in runoff may be greater after the winter wheat is harvested and a substantial amount of wheat residue has accumulated on the soil surface. Additional studies are needed to determine if winter wheat strips that are harvested are effective in reducing microbial transport.

If harvested winter wheat strips are found to reduce microbial transport, it may be desirable to establish multiple strips, each containing different crops, near the edge of a field. Manure should not be applied to any of the filter strips. As an example, the crop rotation employed on the farm in the present study was grain sorghum, soybean, and winter wheat. Three strips could be established at the edge of a field, each planted to one of the three crops used in the rotation. Therefore, at least one of the strips would contain wheat residue from the previous cropping season. The use of multiple crop strips for filtering overland flow would also provide an increased dilution benefit from rainfall occurring over a larger non-manured area.

Conclusions

The 1.4 m long strips of actively growing winter wheat examined in this investigation did not significantly reduce the transport of phages, total coliforms, *E. coli*, and enterococci in runoff. For the plots that received manure, no significant differences in transport of phages were found among the three manure application rates. However, the application of manure to meet the 4-year P requirement resulted in *E. coli* and enterococci loads that were significantly greater than the 1-year P requirement. Measurements for each of the microbes varied significantly among the three rainfall simulation runs. Counts for phages, *E. coli*, and enterococci were significantly less for the first rainfall simulation run than for the second run.

Microbes transported in overland flow are suspended rather than dissolved constituents. As a result, as water infiltrates within a wheat strip, the concentration of suspended materials is reduced because of the decrease in overland flow volume. However, the increase in concentrations of suspended materials due to infiltration may be offset by the dilution effect of rainfall occurring over the wheat strip area.

Microbial transport loads would be expected to 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 investigation. An actively growing 1.4 m winter wheat strip was not found to significantly reduce microbial transport following the application of varying rates of beef cattle manure.

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