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Narrow Grass Hedge Control of Nutrient Loads Following Variable Manure Applications

J. E. Gilley, L. M. Durso, R. A. Eigenberg, D. B. Marx, B. L. Woodbury

Abstract. *The effectiveness of a narrow grass hedge in reducing runoff nutrient loads 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. Runoff water quality was measured during three 30 min simulated rainfall events. Manure application rate significantly affected dissolved phosphorus (DP) and total phosphorus (TP) loads in runoff on the plots without a grass hedge. However, DP and TP loads were not significantly affected by manure application rate on the plots containing a hedge. The hedge reduced the mean load of DP in runoff from 0.69 to 0.08 kg ha^{-1} and the load of TP from 1.05 to 0.13 kg ha^{-1}. When averaged across manure application rates, 0.11 kg NO_3-N ha^{-1}, 0.02 kg NH_4-N ha^{-1}, and 0.49 kg total nitrogen (TN) ha^{-1} were measured from the plots with a hedge, compared to 0.39 kg NO_3-N ha^{-1}, 0.55 kg NH_4-N ha^{-1}, and 2.52 kg TN ha^{-1} from the plots without a hedge. For the plots with a grass hedge, runoff loads of DP and TP where manure was applied were similar to values obtained with no manure application. Each of the runoff water quality parameters was significantly affected by runoff rate. A narrow grass hedge placed on the contour across a hillslope significantly reduced runoff nutrient loads following variable manure applications.*

Keywords. *Erosion, Grass filters, Land application, Manure management, Manure runoff, Nitrogen, Nutrients, Phosphorus, Runoff, Water quality.*

Zones of vegetation through which sediment and pollutant flow are directed before being discharged to a concentrated flow channel are defined as vegetative filter strips (Haan et al., 1994). To be effective, vegetative filter strips are usually located on the contour perpendicular to the direction of flow. The effectiveness of naturally occurring vegetative filter strips in removing sediment and dissolved solids has been reported (Dillaha et al., 1988; Cooper and Gilliam, 1987). Constructed vegetative filter strips have also been shown to substantially reduce suspended and dissolved constituents in runoff (Dillaha et al., 1989; Hayes et al., 1984; Magette et al., 1989).

Vegetative filter strips remove solids by three principal mechanisms: (1) deposition of bed load material resulting from smaller flow velocities and transport capacity, (2) trapping of suspended solids in the litter that has accumulated on the soil surface, and (3) trapping of suspended materials that move into the soil matrix along with infiltrated water (Haan et al., 1994). Some deposition of sediment occurs upslope from the vegetative filter strip, but most of the suspended solids are deposited in a bed load or suspended load deposition zone located within the vegetative area.

It is recommended that the width of a vegetative filter strip (the flow length of water through the strip) be based on sediment delivery calculated using RUSLE2 (Renard et al., 1997) and the ratio of the filter strip width to the length of the flow path from the contributing area (USDA-NRCS, 2007, 2010a). The minimum recommended vegetative filter strip width is 6 m. The filter strip should contain vegetation that is able to withstand partial burial from sediment deposition and that is tolerant of herbicides that are used in the area.

A level spreader may be necessary under some situations to convert potentially erosive concentrated flow to sheet flow before it is released to a filter strip (USDA-NRCS, 1999). The level spreader should run linearly along the entire width of the filter strip to which it discharges. Establishing sheet flow enhances pollutant filtering and infiltration within the filter strip and reduces the potential for erosion.

Narrow Grass Hedges

Placement of narrow grass hedges along the slope contour provides benefits similar to those of vegetative filter strips (Dewald et al., 1996; 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). Narrow grass hedges also promote sediment deposition and berm formation and diffuse and spread overland flow (Dabney et al., 1995, 1999).

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Runoff nutrient losses are reduced significantly by narrow grass hedges (Eghball et al., 2000; Owino et al., 2006). Gilley et al. (2008) found that narrow grass hedges reduced runoff loads of dissolved P (DP), total phosphorus (TP), NO_3-N, NH_4-N, and total nitrogen (TN) from soils with a range of residual soil nutrient values. In that study, mean runoff rates on the plots with and without a narrow grass hedge were 17 and 29 mm, and sediment delivery rates were 0.12 and 1.46 Mg ha^{-1}, respectively.

Sediment trapping by narrow grass hedges results primarily from upslope ponding by the hedges rather than by the filtering action that occurs within vegetative filter strips (Meyer et al., 1995). The placement of narrow grass hedges at intervals along a hillslope causes much of the sediment carried by overland flow to move only a short distance before it is deposited. In contrast, substantial quantities of sediment are deposited within vegetative filter strips (Haan et al., 1994).

Narrow grass hedges are planted at short distances along the slope contour to allow multiple passes of farm implements (Meyer et al., 1995; Dewald et al., 1996), while vegetative filter strips are usually placed at the bottom of a hillslope. The horizontal spacing between narrow grass hedges is determined using the lesser of (1) the horizontal distance where the change in vertical elevation is 2 m, or (2) the RUSLE2 (Renard et al., 1997) "L" value that restricts soil loss from the field to the allowed limit (USDA-NRCS, 2010b).

The width of narrow grass hedges, which is also the flow path through the hedge, is much smaller than that of vegetative filter strips. It is recommended that narrow grass hedge widths be the larger of 1 m or 0.75 times the change in upslope vertical elevation (USDA-NRCS, 2010b). Broadcast or drilled seed should be sown in strips at least 1 m wide. Grass hedges seeded with a row planter should be at least two rows wide.

Narrow grass hedges have been effectively used in combination with vegetative filter strips (Blanco-Canqui et al., 2004a). When placed immediately above vegetative filter strips, narrow grass hedges minimized soil and nutrient losses resulting from interrill and concentrated flow (Blanco-Canqui et al., 2004b, 2006).

Impacts of Manure Application

Manure can be effectively used for crop production and soil improvement because it contains nutrients and organic matter (Eghball and Power, 1994). Runoff and erosion have been reduced significantly on sites receiving long-term manure application at appropriate rates (Gilley and Risse, 2000). As manure application rates increased, runoff and soil loss values were found to decrease. An increase in soil nutrient content may result in greater runoff nutrient concentrations (Gilley et al., 2007a). However, soil nutrient values on cropland may not significantly impact nutrient yields when rainfall occurs soon after manure application (Eghball et al., 2002).

The objectives of this study were (1) to determine the effects of a narrow grass hedge and varying manure application rates on runoff nutrient loads (mass per unit area) occurring soon after manure application, and (2) to compare the effects of a narrow grass hedge, varying manure application rates, and different overland flow rates on runoff nutrient loads (mass per unit area per unit time).

Materials and Methods

Study Site Characteristics

This field study was conducted at the University of Nebraska Rogers Memorial Farm located 18 km east of Lincoln, Nebraska. The soil at the site developed in loess under prairie vegetation. The Aksarben silty clay loam (fine, smectitic, mesic Typic Argiudoll) contained 11% sand, 54% silt, and 35% clay (Kettler et al., 2001), and the top 15 cm of the soil profile contained 18.5 g kg^{-1} of organic carbon. This soil is moderately well drained despite the permeability being moderately slow.

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. Sorghum was planted during the 2008 season, and soil on the site remained undisturbed following sorghum harvest. Herbicide (glyphosate) was applied during the study as needed to control weed growth on the plot areas that were not covered by a grass hedge. Special care was taken so that herbicide was not applied to the vegetated area.

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. Experimental treatments included the presence or absence within the plot of a 1.4 m wide switch grass (*Panicum virgatum*) hedge, varying manure application rates, and different runoff rates. The existence or absence of a grass hedge was the main plot treatment, and manure application rate was the subplot treatment (fig. 1). Calculations of nutrient load 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 July 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 placed in the pens in September 2008 at a rate of 36 head per pen (50 m^2 per head).

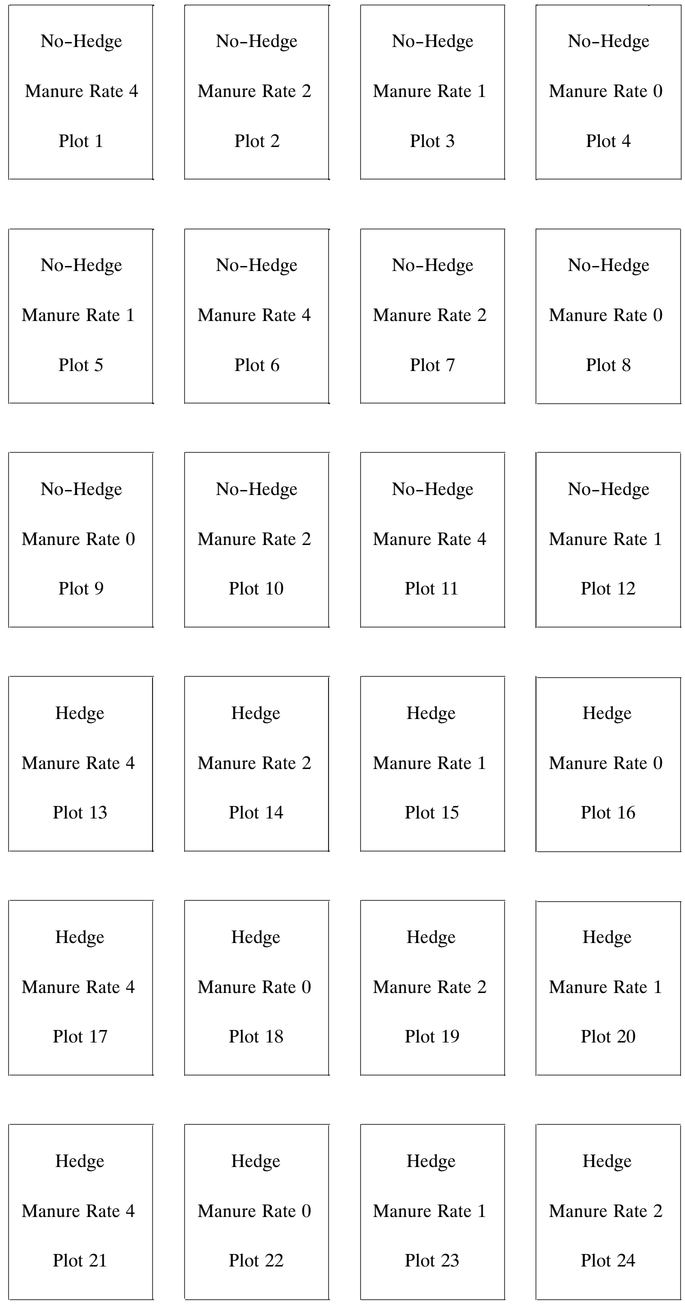

Figure 1. Schematic showing the plot layout, the hedge and no-hedge treatments, and the manure application rates.

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}) (table 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).

This study was conducted to measure nutrient loads in runoff immediately after manure application. The characteristics of the manure collected each week were measured. Appropriate manure application amounts were then applied to the six plots on which rainfall simulation tests were conducted each week.

Rainfall Simulation Procedures

Water used in the rainfall simulation tests was obtained from an irrigation well. Nutrient contents reported in this article are the difference between nutrient measurements in runoff and those in the irrigation water. Measured mean concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were 0.16, 0.16, 13.7, 0.01, and 13.7 mg L^{-1}, respectively. The irrigation water had a mean EC of 0.81 dS m^{-1} and a pH of 7.6.

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

Table 1. Manure characteristics and application rates of nitrogen and phosphorus.

N Application Rate[a]	NO_3-N (g kg^{-1})[b]	NH_4-N (g kg^{-1})	Total N (g kg^{-1})	Total P (g kg^{-1})	Water Content (g kg^{-1})	EC (dS m^{-1})[c]	pH	Total N (kg ha^{-1})	Total P (kg ha^{-1})
1	0.01	0.40	23	6.9	211	30	8.3	151	92
2	0.01	0.40	23	6.9	211	30	8.3	302	184
4	0.01	0.40	23	6.9	211	30	8.3	604	367

[a] Manure was applied at a rate required to meet a 1, 2, or 4 year corn N requirement.
[b] Nutrient concentration was determined on a dry basis.
[c] EC = electrical conductivity; EC and pH were determined in 1:5 manure:water ratio.

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 tests 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. Accumulated runoff was agitated to maintain suspension of solids. One runoff sample was collected for water quality analysis, and an additional sample was obtained for sediment analysis.

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 using a Lachat system (Zellweger Analytics, Milwaukee, Wisc.). Samples that were not centrifuged were analyzed for TP (Johnson and Ulrich, 1959), TN (Tate, 1994), pH, and EC. The samples of a known volume obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment content.

The upslope areas contributing runoff to grass hedges under typical field conditions are much larger than those employed in this study. Runoff quantities entering the grass hedges increase as the upslope contributing area becomes larger. Therefore, additional field tests were conducted to identify the effects of varying flow rate on nutrient transport. Water was added to the test plots to simulate increased flow rates resulting from larger upslope contributing areas. The addition of inflow to test plots to simulate greater slope lengths is a well established experimental procedure (Monke et al., 1977; Laflen et al., 1991).

Simulated overland flow was applied at the upslope end of each plot after the first 30 min of the third simulation run, while rainfall application continued at 70 mm h^{-1}. Inflow was added in four successive increments to produce average runoff rates of 2.63, 5.85, 6.71, and 8.90 kg min^{-1} on the plots with a grass hedge and 5.42, 9.54, 10.22, and 13.35 kg min^{-1} on the plots without a hedge. Greater infiltration rates within the plots containing a grass hedge resulted in smaller runoff rates. A narrow mat made of green synthetic material often used as an outdoor carpet was placed on the soil surface beneath the inflow device. The mat helped to prevent scouring and distributed the flow more uniformly across the plot.

A mean overland flow rate of 1.05 kg min^{-1} was measured without the addition of simulated overland flow. The largest overland flow rate was 11.13 kg min^{-1}, or approximately 11 times the value without the addition of inflow. The use of runoff quantities substantially larger than 11.13 kg 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 runoff conditions for the previous increment had been reached and samples for nutrient and sediment analyses had been collected. Steady runoff was determined using the stage recorder and flume. Each simulated overland flow increment was maintained for approximately 8 min.

Statistical Analyses

Analysis of variance (SAS, 2003) was performed to determine the effects of a narrow grass hedge and manure application rate on runoff nutrient load, and the effects of a narrow grass hedge, manure application rate, and simulated overland flow rate on the nutrient yield in runoff. If a significant difference was identified, the least significant difference (LSD) test was used to identify differences among experimental treatments. A probability level <0.05 was considered significant.

Results and Discussion

Runoff Characteristics

Phosphorus Load

The hedge × manure application rate interaction was significant for DP, PP, TP, and EC (table 2). Manure application rate significantly affected the runoff load of DP and TP on the plots without a hedge (figs. 2 and 3, respectively). However, DP and TP load was not significantly affected by manure application rate when a narrow grass hedge was present. The narrow grass hedge reduced the mean load of DP in runoff from 0.69 to 0.08 kg ha^{-1} and the mean load of TP from 1.05 to 0.13 kg ha^{-1}.

The 1.4 m wide grass hedge used in this study covered approximately 35% of the total 4 m plot width. As a result, nutrient 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 DP and TP load in runoff from the plots with a grass hedge was larger than that which could be attributed simply to a smaller upslope contributing area. Sorption of nutrients by vegetation or soil within the hedge may have occurred. Accurate estimation of the effects of runoff contributing area on nutrient transport was difficult because nutrient sorption within a narrow grass hedge system is not well defined.

Regression equations relating DP and TP load to manure application rate are presented in figures 4 and 5, respectively.

Table 2. Effects of hedge and manure application rate on runoff water quality parameters averaged over the three rainfall simulation runs.

Variable		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)	Erosion ($Mg\ ha^{-1}$)
Hedge	Hedge	0.08	0.05	0.13	0.11	0.02	0.49	0.78	7.62	6.4	0.06
	No-hedge	0.69	0.36	1.05	0.39	0.55	2.52	1.21	7.81	14.4	0.21
	$LSD_{0.05}$	0.30	0.16	0.46	0.10	0.19	1.24	0.15		5.6	
Manure rate ($Mg\ ha^{-1}$)	0	0.04	0.03	0.07	0.32	0.01	0.63	0.74	7.77	10.5	0.08
	16	0.24	0.12	0.36	0.26	0.16	1.27	0.88	7.71	10.8	0.12
	31	0.54	0.29	0.83	0.26	0.43	1.89	1.08	7.65	11.0	0.17
	62	0.72	0.39	1.11	0.15	0.53	2.22	1.29	7.75	9.4	0.17
	$LSD_{0.05}$	0.43	0.22	0.65				0.21			
ANOVA		Pr > F									
Hedge		0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.06	0.04	0.07
Manure rate		0.03	0.02	0.02	0.42	0.06	0.32	0.01	0.18	0.96	0.27
Hedge × manure rate		0.04	0.04	0.04	0.35	0.07	0.49	0.01	0.23	0.87	0.42

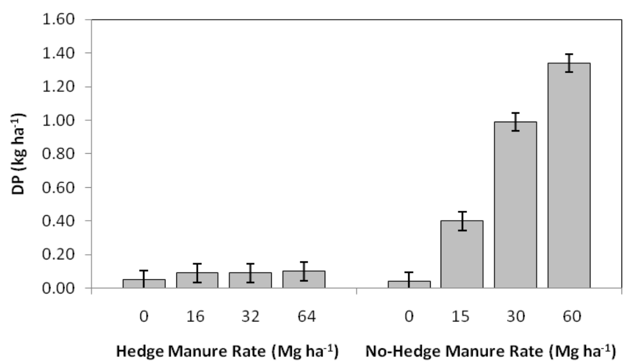

Figure 2. Load of dissolved phosphorus (DP) in runoff as affected by manure application rate for the hedge and no-hedge conditions. Nutrient load values are averages from three rainfall simulation runs. Vertical bars are standard errors.

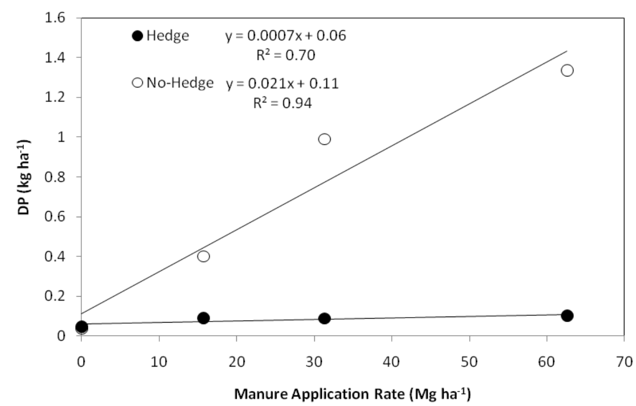

Figure 4. Load of dissolved phosphorus (DP) in runoff as affected by manure application rate for the hedge and no-hedge treatments.

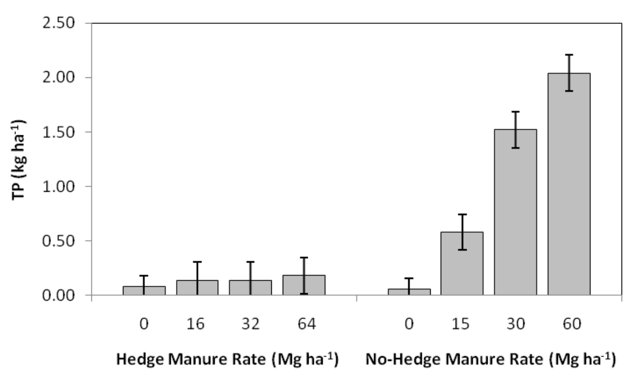

Figure 3. Load of total phosphorus (TP) in runoff as affected by manure application rate for the hedge and no-hedge conditions. Nutrient load values are averages from three rainfall simulation runs. Vertical bars are standard errors.

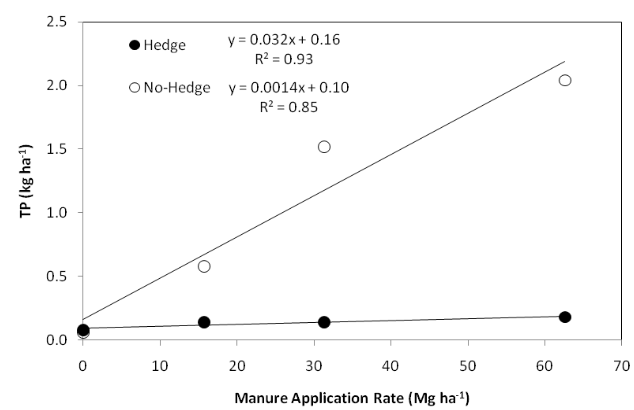

Figure 5. Load of total phosphorus (TP) in runoff as affected by manure application rate for the hedge and no-hedge treatments.

The narrow grass hedge can be seen to have been very effective in reducing DP and TP loads. For the plots with a grass hedge, runoff loads of DP and TP on the plots where manure was applied were similar to values obtained with no manure application. At present, the manure application rate for which a narrow grass hedge is no longer effective is unknown.

Nutrient transport in runoff as affected by time following the application of manure to cropland was examined by Gilley et al. (2007b). Concentrations of DP and TP in runoff declined throughout the year on sites where cattle and swine manure were applied but not incorporated into the soil. Therefore, the phosphorus loads measured in this study immediately after manure applications are the largest that would be expected.

Nitrogen Yield

No significant hedge × manure application rate interaction was found in this study for NO_3-N, NH_4-N, or TN (table 2). Manure application rate did not significantly affect runoff loads of NO_3-N, NH_4-N, and TN. Relatively large residual soil nitrogen may have influenced runoff nitrogen loads. The runoff load of NO_3-N, NH_4-N, and TN was significantly less

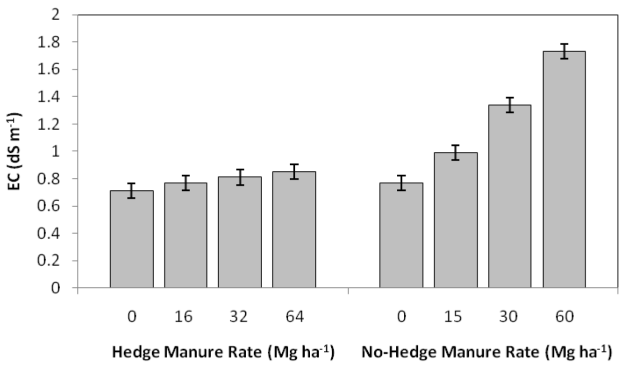

Figure 6. EC of runoff as affected by manure application rate for the hedge and no-hedge conditions. EC values are averages from three rainfall simulation runs. Vertical bars are standard errors.

with the narrow grass hedge than without a hedge (table 2). When averaged across manure application rates, 0.11 kg NO_3-N ha^{-1}, 0.02 kg NH_4-N ha^{-1}, and 0.49 kg TN ha^{-1} were measured in runoff from the plots with a narrow grass hedge compared to 0.39 kg NO_3-N ha^{-1}, 0.55 kg NH_4-N ha^{-1}, and 2.52 kg TN ha^{-1} from the plots without a hedge.

Measurements of EC, pH, Runoff, and Erosion

Significant hedge × manure application rate interactions were found for EC (table 2). When there was no narrow grass hedge, EC significantly increased as manure application rate became larger (fig. 6). However, no significant differences in EC were found among manure application rates when a narrow grass hedges was in place. Measurements of pH in runoff were not significantly affected by a narrow grass hedge or manure application rate (table 2).

Water was added to the plots just before rainfall simulation testing began to provide more uniform antecedent soil water conditions among experimental treatments. Runoff was significantly less when a narrow grass hedge was present than without a hedge, averaging 6.4 and 14.4 mm, respectively (table 2). Increased infiltration rates on the vegetated and ponded areas may have been responsible for the smaller runoff rates on the plots containing a grass hedge. Erosion with and without a hedge was 0.06 and 0.21 Mg ha-^{1}, respectively (table 2). Manure application rate did not significantly affect runoff or erosion.

The narrow grass hedge reduced the total amount of runoff by 56% (table 2). The large reduction in runoff caused by the narrow grass hedge resulted in smaller nutrient loads. The runoff loads of DP and TP on the plots with a hedge were both reduced by 88%. Thus, other factors in addition to a decrease in runoff volume are responsible for the reduction in nutrient load on the plots containing a hedge.

In this study, the ratio of the area with a grass hedge to total plot area was 0.35 (1.4 m / 4.0 m). Under normal field conditions, the upslope area above the grass hedge is much larger than that used in this investigation. Thus, the reduction in runoff volume caused by a narrow grass hedge under field conditions would be expected to be less.

McGregor et al. (1999) measured runoff and erosion from cotton plots in Mississippi with and without narrow grass hedges. The annual ratio of erosion for no-till and conventional-till plots with hedges to those without hedges averaged 0.43 and 0.25, respectively. Gilley et al. (2000) found that tilled plots with residue from corn plants and narrow grass hedges in Iowa averaged 22% less runoff and 57% less erosion than comparable plots without hedges. Cullum et al. (2007) measured runoff and erosion from cotton plots in Mississippi with and without narrow grass hedges. The ratio for annual erosion for the cotton plots with hedges to those without hedges averaged 0.62.

Runoff Characteristics as Affected by Overland Flow

The hedge × manure application rate × runoff rate interaction was significant for EC (table 3). Significant hedge × manure application rate interactions were found for DP, PP, TP, NH_4-N, TN, and EC. The hedge × runoff rate interaction was significant for DP, NH_4-N, EC, and pH. Significant manure application rate × runoff rate interactions were found for DP and EC.

Measuring the effects of varying flow rate on runoff characteristics provides additional information on the effectiveness of narrow grass hedges in reducing nutrient transport under varying field and rainfall conditions. Because the upslope contributing area existing under normal field conditions is much larger than that provided by the 4 m long experimental plots, additional overland flow was introduced at the top of the plots to simulate greater plots lengths. In addition, rainfall intensity and duration are highly variable. By relating nutrient load to flow rate, the experimental results are applicable to a larger range of rainfall and runoff conditions.

Capturing and storing all of the runoff that occurred during the experimental tests where simulated overland flow was introduced was not practical. Therefore, nutrient and sediment samples were collected at one point in time for an existing steady-state runoff rate, and load values per unit time are reported for this portion of the study.

Phosphorus Measurements

The mean DP load was significantly less for the plots with a narrow grass hedge than for those without a hedge, averaging 8.9 and 29.0 g ha^{-1} min^{-1}, respectively (table 3). Significant differences in DP load occurred among manure application rates, with values ranging from 2.1 to 38.4 g ha^{-1} min^{-1}. The DP load for the four largest runoff rates on the plots without a hedge was significantly greater than the DP load for the plots with a hedge (fig. 7).

The narrow grass hedge reduced the mean TP load from 36.0 to 13.1 g ha^{-1} min^{-1} (table 3). The TP load was significantly less for the initial runoff rate than for the other runoff rates. No significant differences in TP load were found among the four largest runoff rates.

Nitrogen Measurements

The presence of the narrow grass hedge did not significantly affect the runoff load of NO_3-N (table 3). The NO_3-N load of 11.0 g ha^{-1} min^{-1} measured for runoff rate four was significantly greater than that of the other runoff rates. No significant differences in NO_3-N load were found among the first four runoff rates.

The mean load for NH_4-N was less for the plots with a hedge than for those without a hedge, averaging 1.7 and 10.2 g ha^{-1} min^{-1}, respectively (table 3). For the plots containing a hedge, no significant differences in the load of NH_4-N was found among the various runoff rates (fig. 8). However, for the plots without a hedge, the load of NH_4-N

Table 3. Runoff water quality parameters as affected by hedge, manure application rate, and runoff rate.

Variable		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})	Total N (g ha^{-1} min^{-1})	EC (dS m^{-1})	pH	Erosion (kg ha^{-1} min^{-1})
Hedge	Hedge	8.9	4.2	13.1	7.3	1.7	65	0.82	7.66	8.9
	No-hedge	29.0	7.0	36.0	8.7	10.2	129	0.77	7.76	9.8
	$LSD_{0.05}$	2.3	1.0	2.9		1.9	15	0.01	0.03	
Manure rate (Mg ha^{-1})	0	2.1	2.0	4.1	7.9	0.1	62	0.75	7.74	9.9
	16	11.4	3.2	14.6	10.4	2.2	87	0.77	7.72	8.6
	31	23.8	6.1	29.9	8.7	7.9	109	0.80	7.69	9.8
	62	38.4	11.1	49.5	5.0	13.8	130	0.84	7.70	9.3
	$LSD_{0.05}$	3.2	1.2	4.1		2.1	22	0.01		
Runoff rate	One	8.2	4.4	12.6	6.0	3.0	34	0.83	7.77	2.5
	Two	20.1	7.4	27.5	7.5	7.1	83	0.79	7.78	5.7
	Three	21.9	5.8	27.7	7.6	7.2	112	0.78	7.71	11.2
	Four	20.8	4.8	25.6	7.9	6.2	113	0.78	7.67	10.7
	Five	23.6	5.5	29.1	11.0	6.4	143	0.78	7.64	16.7
	$LSD_{0.05}$	2.9	1.3	4.0	2.8	1.8	15	0.01	0.03	3.1
ANOVA		Pr > F								
Hedge		0.01	0.02	0.01	0.46	0.01	0.01	0.01	0.01	0.76
Manure rate		0.01	0.01	0.01	0.17	0.01	0.01	0.01	0.44	0.96
Runoff rate		0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Hedge × manure rate		0.01	0.01	0.01	0.88	0.01	0.01	0.01	0.23	0.59
Hedge × runoff rate		0.03	0.06	0.47	0.18	0.02	0.16	0.01	0.01	0.82
Manure rate × runoff rate		0.01	0.52	0.08	0.23	0.06	0.77	0.01	0.61	0.31
Hedge × manure rate × runoff rate		0.13	0.89	0.64	0.84	0.46	0.44	0.01	0.56	0.10

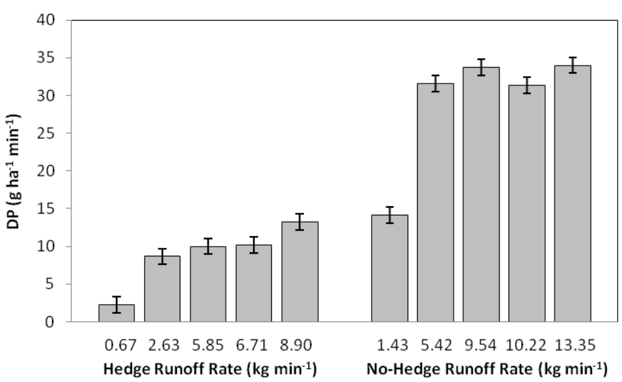

Figure 7. Load of dissolved phosphorus (DP) in runoff as affected by runoff rate for the hedge and no-hedge conditions. Nutrient yield values were averaged across manure application rates. Vertical bars are standard errors.

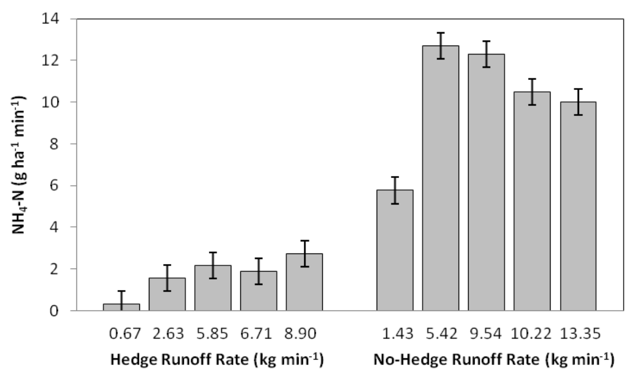

Figure 8. Load of NH_4-N in runoff as affected by runoff rate for the hedge and no-hedge conditions. Nutrient yield values were averaged across manure application rates. Vertical bars are standard errors.

was significantly less for the initial runoff rate than for the other runoff rates. The load of NH_4-N from plots with a grass hedge varied from 0.32 to 2.72 g ha^{-1} min^{-1}, which was significantly less than the 5.77 to 12.66 g ha^{-1} min^{-1} measured for the plots without a hedge (fig. 8).

The mean TN load was significantly less for the plots with a hedge than for those without a hedge, averaging 65 and 129 g ha^{-1} min^{-1}, respectively (table 3). Runoff rate significantly affected the TN load, with values varying from 34 to 143 g ha^{-1} min^{-1}.

EC, pH, and Erosion Measurements

Analysis of variance indicated that the presence of a hedge, manure application rate, and inflow rate each significantly affected EC measurements (table 3). Runoff measurements of EC were larger on the plots with a grass hedge than on those without a hedge because of smaller runoff rates and less dilution on the plots with a hedge. Measurements of EC consistently increased as manure application rate increased.

Both the presence of a narrow grass hedge and runoff rate significantly affected pH measurements (table 3). Measurements of pH were less on the plots with a hedge than on those without a hedge again because of smaller runoff rates and less dilution on the plots with a hedge. As runoff rate increased, pH measurements usually decreased.

Erosion rates were significantly affected by runoff rate and varied from 2.5 to 16.7 kg ha^{-1} min^{-1} (table 3). The increase in erosion rate with runoff rate is well established.

Narrow Grass Hedges as a Best Management Practice

Previous studies have shown that narrow grass hedges can effectively reduce nutrients in runoff from soils with varying residual soil nutrient values. Results from this investigation show that narrow grass hedges can also reduce nutrient loads in runoff occurring soon after manure application. The greatest reductions in nutrient loads were found on those plots that received the largest manure applications.

Manure is usually applied 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 this study to be an effective best management practice on cropland that receives multi-year applications of manure.

The effectiveness of a single grass hedge in reducing runoff nutrient loads 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. Experimental results from this study show that nutrient load increases with flow rate. A single grass hedge was capable of effectively reducing nutrients in runoff for the flow rates examined in this investigation.

At present, the mechanisms responsible for reducing runoff nutrient load within narrow grass hedge systems have not been clearly identified. Narrow grass hedges cause sediment to be deposited immediately above the hedge. Since manure was applied immediately before the rainfall simulation tests, the manure particles themselves may have been trapped on the soil surface. The slope gradients above a grass hedge may also be considerably less, increasing the length of time that overland flow is in contact with the soil surface.

Nutrients contained in overland flow may also be adsorbed by vegetative materials within the grass hedge. The nutrient sorption capacity of common grasses has been identified. Removal of vegetative materials from the grass hedge area reduces the accumulation of nutrients. If vegetative materials are not removed, the hedge will accumulate organic matter and release nutrients contained in the vegetative materials.

The use of narrow grass hedges is only one of several best management practices available for reducing sediment and nutrient loads in overland flow. The presence of a grass hedge system should not be viewed as an opportunity to apply fertilizer or manure at rates in excess of crop nutrient requirements. Narrow grass hedges are best used as one part of a combination of several soil and water conservation best management practices.

Conclusions

Narrow grass hedges significantly reduced the mean load of DP, PP, TP, NH_4-N, and TN in runoff for conditions both with and without the introduction of simulated overland flow. Runoff loads of DP, PP, and TP were significantly influenced by manure application rate. Runoff rate significantly influenced each of the measured water quality parameters.

The water quality measurements obtained in this study were for conditions occurring soon after the addition of manure without incorporation. Therefore, the experimental results may represent a nutrient load extreme. Nutrient load values would be expected to decrease over time following manure application.

Runoff nutrient loads would be expected to be different at other locations with varying soil characteristics. The quantitative values reported in this study are also only strictly applicable for the slope length, steepness, cropping, and management conditions used in this investigation. For the given experimental conditions, narrow grass hedges were very effective in reducing nutrient loads in runoff occurring soon after manure application.

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