5-1-2008

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Gilley, John E.; Eghball, Bahman; and Marx, David B., "Narrow Grass Hedge Effects on Nutrient Transport Following Compost Application" (2008). *Biological Systems Engineering: Papers and Publications*. 28.
https://digitalcommons.unl.edu/biosysengfacpub/28

NARROW GRASS HEDGE EFFECTS ON NUTRIENT TRANSPORT FOLLOWING COMPOST APPLICATION

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ABSTRACT. *The placement of stiff-stemmed grass hedges on the contour along a hillslope has been shown to decrease nutrient transport in runoff. This study was conducted to measure the effectiveness of a narrow grass hedge in reducing runoff nutrient transport from plots with a range of soil nutrient values. Composted beef cattle manure was applied at dry weights of 0, 68, 105, 142, and 178 Mg ha*$^{-1}$ *to a silty clay loam soil and then incorporated by disking. Soil samples were collected 243 days later for analysis of water-soluble phosphorus (WSP), Bray and Kurtz No. 1 phosphorus (Bray-1 P),* NO_3*-N, and* NH_4*-N. Three 30 min simulated rainfall events, separated by 24 h intervals, were then applied. The transport of dissolved phosphorus (DP), total P (TP),* NO_3*-N,* NH_4*-N, total nitrogen (TN), runoff, and soil erosion were measured from 0.75 m wide × 4.0 m long plots. Compost application rate significantly affected soil measurements of WSP, Bray-1 P, and* NO_3*-N content. The transport of DP, TP,* NO_3*-N,* NH_4*-N, TN, runoff, and soil erosion was reduced significantly on the plots with a grass hedge. Mean runoff rates on the hedge and no-hedge treatments were 17 and 29 mm, and erosion rates were 0.12 and 1.46 Mg ha*$^{-1}$*, respectively. Compost application rate significantly affected the transport of DP, TP, and* NO_3*-N in runoff. The experimental results indicate that stiff-stemmed grass hedges, planted at selected downslope intervals, can significantly reduce the transport of nutrients in runoff from areas with a range of soil nutrient values.*

Keywords. *Grass filters, Land application, Manure management, Manure runoff, Nitrogen movement, Nutrient losses, Phosphorus, Runoff, Sediment detention, Water quality.*

The use of stiff-stemmed grass hedges (barriers) has been shown to effectively reduce soil loss from cropland areas (Kemper et al., 1992). Improved soil hydraulic properties beneath stiff-stemmed grass hedge systems may also decrease runoff (Rachman et al., 2004a, 2004b). Narrow grass hedges promote sediment deposition and berm formation, and diffuse and spread overland flow (Dabney et al., 1995). The potential for concentrated flow is reduced since stiff-stemmed grass hedges are usually planted along the contour at relatively short intervals that allow multiple passes of farm implements (Meyer et al., 1995). As a result, much of the sediment carried by overland flow moves only a short distance before it is deposited.

Stiff-stemmed grass hedges significantly reduced runoff and soil loss from cotton plots in Mississippi (McGregor et al., 1999; Cullum et al., 2007). Under no-till conditions, plots in southwest Iowa with corn residue and stiff-stemmed hedges averaged 52% less runoff and 57% less soil loss than comparable plots without grass hedges (Gilley et al., 2000). Under tilled conditions, the plots in southwest Iowa with corn residue and grass hedges averaged 22% less runoff and 57% less soil loss than comparable plots without grass hedges.

The enhanced infiltration within stiff-stemmed grass hedge systems helps to reduce runoff nutrient loads. Sediment containing adsorbed nutrients may be deposited in the ponds formed immediately above grass hedges. Owino et al. (2006) found that nutrient runoff losses from a clay loam soil in Kenya were also significantly reduced by stiff-stemmed grass hedges.

Stiff-stemmed grass hedges effectively reduced nutrient losses in runoff following manure and fertilizer application on a cropland site in Iowa (Eghball et al., 2000). A single narrow grass hedge reduced runoff concentrations of dissolved P (DP) by 47%, total P (TP) by 40%, and NH_4-N by 60% during the wet simulation run on no-till plots receiving manure, compared to similar plots without hedges. On the disked plots with a grass hedge, concentrations of DP, TP, and NH_4-N in runoff decreased by 21%, 38%, and 52%, respectively.

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

Manure has been used effectively for crop production and soil improvement because it contains nutrients and organic matter (Eghball and Power, 1994). Runoff and soil loss values are reduced substantially on sites receiving long-term manure application (Gilley and Risse, 2000). As manure application rates increased, runoff and soil loss rates decreased. However, an increase in soil nutrient content can result in greater runoff nutrient concentrations (Gilley et al., 2007a).

Submitted for review in November 2007 as manuscript number SW 7264; approved for publication by the Soil & Water Division of ASABE in May 2008.

This article is a contribution from the USDA-ARS in cooperation with the Agricultural Research Division, University of Nebraska, Lincoln.

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When rainfall occurs soon after manure application, soil nutrient values on cropland areas may not significantly impact runoff nutrient content (Eghball et al., 2002b). Gilley et al. (2007b) examined runoff nutrient transport as affected by time following the application of manure to cropland areas. Concentrations of DP, TP, and NH_4-N in runoff were found to decline throughout the year on the no-till cattle and no-till swine manure treatments.

The specific objectives of this study were to (1) measure the effects of soil sampling depth, grass hedge, and compost application rate on soil characteristics; (2) determine the effects of grass hedge and compost application rate on runoff nutrient load; and (3) compare the effects of grass hedge, compost application rate, and inflow rate on nutrient transport rate in runoff.

MATERIALS AND METHODS

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 and had a mean slope of 5%. The Sharpsburg silty clay loam soil (fine, smectitic, mesic Typic Argiudoll) contained 11% sand, 54% silt, and 35% clay (Kettler et al., 2001) and 18.5 g kg^{-1} of organic C in the top 15 cm of the soil profile. This soil is moderately well drained, and permeability is moderately slow.

The study site had been cropped using a grain sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), winter wheat (*Triticum aestivum* L. cv. Pastiche) rotation, under a long-term continuous no-till management system with controlled wheel traffic. The study area was planted to soybean during the 2002 cropping season. Soil on the site remained undisturbed following soybean harvest. Herbicide (glyphosate) was applied as needed to control weed growth.

Soil samples for study site characterization were obtained on 7 July 2003 at sampling depths of 0-5 cm and 5-15 cm. For each depth increment, samples were collected at existing soil water conditions from several locations on each plot and composited. The plot area immediately above the grass hedge was used to collect soil samples on the hedge treatments.

Following collection, soil samples were transported to the lab, clods were broken by hand, and the samples were air-dried. The dried samples were ground prior to analyses. The Murphy and Riley (1962) procedure, which involves shaking 2 g of soil for 5 min in 20 mL of deionized water, was used to determine water-soluble phosphorus (WSP). As an index of P availability, the Bray-1 P procedure (Bray and Kurtz, 1945) provides a relative estimate of P concentration in the soil solution that limits the growth of plants.

Soil NO_3-N and NH_4-N concentrations (extracted using a 2 M KCl solution) were measured with a flow injection analyzer using a spectrophotometer (Lachat system from Zellweger Analytics, Milwaukee, Wisc.) (Stevenson, 1982). The mean content of WSP, Bray-1 P, NO_3-N, and NH_4-N at the 0-5 cm soil sampling depth of the hedge and no-hedge treatments was 2.1, 30, 12.4, and 5.6 mg kg^{-1}, respectively. Electrical conductivity and pH (Klute, 1994), measured in a 1:1 soil/water ratio, were 0.69 dS m^{-1} and 6.88.

PLOT PREPARATION

Thirty 0.75 m wide × 4 m long plots were established with the longer plot dimension parallel to the slope in the direction of overland flow. Experimental treatments included the presence or absence of a switch grass (*Panicum virgatum*) hedge, compost application rate, and inflow rate. The existence or absence of a grass hedge was the main plot treatment, and compost application rate was the subplot treatment.

The switch grass hedges were established in 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 to allow multiple passes of tillage equipment. The hedges were part of a strip-cropping system, and row crops were planted between the hedge strips.

A 1.4 m wide grass hedge established near the bottom of the hillslope was examined in this study. The grass hedge was located at the downslope portion of 15 of the plots (established using a randomized design) whose slope gradients varied from 4.5% to 5.2%. The other 15 plots (also established using a randomized design) were located immediately below the grass hedge and had slope gradients ranging from 4.4% to 6.1%.

The composted beef cattle manure applied to the study site was obtained from the University of Nebraska Agricultural Research and Development Center near Ithaca. Concentrations of NO_3-N, NH_4-N, TN, and TP in the composted beef cattle manure, determined on a dry weight basis, were 1.22, 0.41, 9.45, and 5.32 g kg^{-1}, respectively. Electrical conductivity and pH, measured in a 1:5 compost/water ratio, were 17.2 dS m^{-1} and 7.2.

Compost was applied by hand on 7 November 2002 at rates of 0, 68, 105, 142, and 178 Mg ha^{-1} (dry weight) using 19 L buckets. These rates were determined from previous mineralization studies conducted to identify the effects of compost application rate on soil P content (Eghball and Power, 1999; Eghball, 2000; Eghball and Barbarick, 2002; Eghball et al., 2002b). Each of the five compost application rates was replicated three times.

Compost would have been applied at a dry rate of 48 Mg ha^{-1} to meet the estimated N requirement to achieve a target corn yield of 9.4 Mg ha^{-1}, assuming 40% N availability during the first year following manure application (Eghball and Power, 1999). The equivalent dry rates of total N that were added were 0, 0.62, 0.96, 1.30, and 1.63 Mg ha^{-1}, while total P was applied at equivalent dry rates of 0, 0.36, 0.56, 0.76, and 0.95 Mg ha^{-1}.

Soil may be transported from its original location during tillage. Therefore, the composted manure was added to an area larger than the final plot dimensions to allow for tillage-induced translocation. Following compost application, the study area was disked to an 8 cm depth across the slope perpendicular to the direction of overland flow. No additional tillage occurred during the study.

RAINFALL SIMULATION PROCEDURES

Water used in the rainfall simulation tests was obtained from an irrigation well. Measured mean concentrations of DP, TP, NO_3-N, NH_4-N, and TN in the irrigation water were: 0.21, 0.21, 16.8, 0.03, and 16.8 mg L^{-1}, respectively. The irrigation water had a mean EC value of 0.69 dS m^{-1} and a pH of 7.27. Nutrient contents reported below are the difference between nutrient measurements in runoff and those in the irrigation water.

Field rainfall simulation tests were conducted from 14 July to 8 August 2003 using a portable rainfall simulator based on the design by Humphry et al. (2002). The simulator provides continuous flow from a single nozzle at an intensity of approximately 70 mm h^{-1} to a pair of 0.75 m wide × 4 m long plots. Experimental procedures established by the National Phosphorus Research Project (NPRP) (Sharpley and Kleinman, 2003) were employed in this study. Two rain gauges were placed along the outer edge of each plot, and one rain gauge was located between the plots.

A single layer of burlap material was placed on the plots to reduce surface disturbance during the pre-wetting process. To provide more uniform antecedent soil water conditions among treatments, water was first added to the plots with a hose until runoff began. The quantity of water required to initiate runoff varied among individual plots depending upon antecedent soil water content. By using a hose, it was possible to pre-wet individual plots without wetting the entire area. It was also much easier to observe when an individual plot became saturated when the simulator was not operating.

The simulator was used to apply rainfall for 30 min. Plots were covered with tarps to prevent the input of natural rainfall after the initial rainfall event. Two additional rainfall simulation tests were conducted for the same duration and intensity at approximately 24 h intervals.

Sheet metal borders located at the top and sides of the plots channeled runoff into a sheet metal lip and collection trough. The trough extended across the bottom of each plot and diverted runoff into aluminum washtubs. The washtubs were weighed after each rainfall simulation event to determine the total mass of runoff plus sediment. Average runoff rate during the third simulation run was 1.50 kg min^{-1}. Accumulated runoff was then agitated to suspend the eroded soil. Two runoff samples were collected for water quality analyses, and two additional runoff samples were obtained for sediment analyses.

After the first 30 min of the third simulation run, runoff was diverted into a flume where a stage recorder was mounted to measure discharge rate. Inflow was then applied at the top of each plot in four successive increments to produce average runoff rates of 4.65, 9.07, 13.23, and 17.20 kg min^{-1}. Rainfall continued during the inflow tests. Mean runoff rates were measured once steady-state conditions had become established as indicated by the stage recorder. Using runoff measurements without the addition of rainfall as a reference, simulated plot lengths were approximately 3.1, 6.0, 8.8, and 11.5 m.

A narrow mat made of green synthetic material, often used as outdoor carpet, was placed on the soil surface beneath the inflow device. The mat helped to prevent scouring and distributed flow more uniformly across the plot. Flow addition for each inflow increment occurred only after steady-state runoff conditions for the previous inflow increment had become established and samples for nutrient and sediment analyses had been collected. Steady-state runoff conditions were determined using the stage recorder and flume. Each inflow increment was maintained for approximately 8 min.

Runoff samples were first filtered and then centrifuged before being analyzed for DP (Murphy and Riley, 1962), NO_3–N, and NH_4–N using a Lachat system (Zellweger Analytics, Milwaukee, Wisc.). Non-centrifuged samples were analyzed for TP (Johnson and Ulrich, 1959) and TN (Tate, 1994). The samples obtained for sediment analysis were dried in an oven at 105°C and then weighed to determine sediment content.

STATISTICAL ANALYSES

Three separate analyses of variance (ANOVA) (SAS, 2003) were performed to determine the effects of (1) soil sampling depth, grass hedge, and compost application rate on soil characteristics; (2) grass hedge and compost application rate on runoff nutrient load; and (3) grass hedge, compost application rate, and inflow rate on nutrient transport rate in runoff. When determining runoff nutrient load, measurements of DP, TP, NO_3–N, NH_4–N, and TN from the three rainfall simulation runs were averaged. A probability level of $P < 0.05$ was considered significant.

RESULTS AND DISCUSSION

SOIL CHARACTERISTICS

The soil depth × hedge × compost rate interaction was significant for WSP ($P = 0.01$), Bray-1 P ($P = 0.03$), and NO_3–N ($P = 0.03$) (table 1). All 2-way interactions were significant for WSP and Bray-1 P. The soil depth × hedge interaction was significant for NH_4–N ($P = 0.01$).

Soil Phosphorus

Significantly greater amounts of WSP and Bray-1 P were found at the 0-5 cm soil sampling depth than at the 5-15 cm depth (table 1). The content of WSP and Bray-1 P averaged 20.2 and 181 mg kg^{-1} at the 0-5 cm depth compared to 1.0 and 8 mg kg^{-1} at the 5-15 cm soil depth. Eghball et al. (2004) also

Table 1. Effects of soil depth, hedge, and compost rate on water-soluble P (WSP), Bray and Kurtz No. 1 P (Bray-1 P), NO_3–N, and NH_4–N content of the soil.

Variable	WSP (mg kg^{-1})	Bray-1 P (mg kg^{-1})	NO_3–N (mg kg^{-1})	NH_4–N (mg kg^{-1})
Soil depth (cm)				
0-5	20.2	181	26.2	5.8
5-15	1.0	8	17.0	3.3
$LSD_{0.05}$	1.8	18	2.8	0.8
Hedge				
Hedge	8.2	72	22.2	2.8
No-hedge	12.9	117	21.1	6.4
$LSD_{0.05}$	1.8	18		0.8
Compost rate (Mg ha^{-1})				
0	1.4	17	9.0	4.5
68	8.5	90	19.1	5.0
105	10.0	90	22.7	4.3
142	14.5	114	29.9	4.2
178	18.5	162	27.4	4.8
$LSD_{0.05}$	2.9	28	4.5	
ANOVA	Pr>F			
Soil depth	0.01	0.01	0.01	0.01
Hedge	0.01	0.01	0.44	0.01
Compost rate	0.01	0.01	0.01	0.65
Soil depth × hedge	0.01	0.01	0.83	0.01
Soil depth × compost rate	0.01	0.01	0.70	0.45
Hedge × compost rate	0.01	0.02	0.18	0.68
Soil depth × hedge × compost rate	0.01	0.03	0.03	0.29

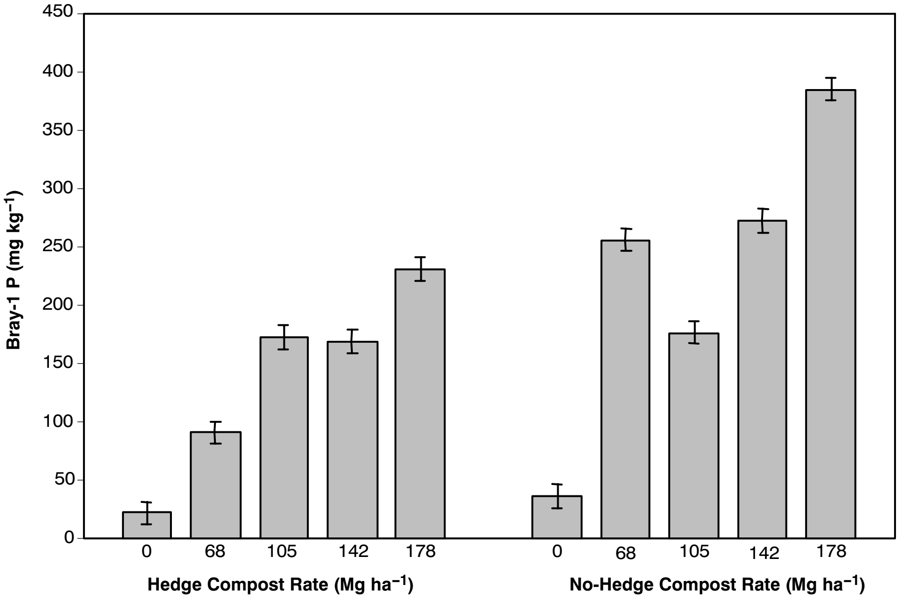

Figure 1. Bray-1 P values at the 0-5 cm soil depth as affected by compost application rate for the hedge and no-hedge condition. Soil test values are averages from three separate plots. Vertical bars are standard errors.

reported elevated P concentrations near the soil surface as a result of manure or compost application. It has been estimated that 10 years of crop removal are needed to reduce soil P content to the level existing before manure application (Eghball et al., 2003).

Measurements of WSP and Bray-1 P were significantly greater on the no-hedge than the hedge treatments. On the no-hedge treatments, WSP and Bray-1 P content averaged 12.9 and 117 mg kg^{-1}, while the content of WSP and Bray-1 P averaged 8.2 and 72 mg kg^{-1} on the hedge treatments (table 1). Previous deposition of sediment may have increased the silt and clay sized soil fractions above the hedge. As a result, nutrient adsorption rates may have been substantially different on the plot areas located above and below the grass hedge. Stiff-stemmed grass hedges have also been shown to influence soil characteristics, including macroporosity (Rachman et al., 2005).

Significant differences in WSP and Bray-1 P content of soil were found among compost application rates (table 1). The WSP content consistently increased as the compost application rate became greater. However, Bray-1 P measurements on the hedge and no-hedge treatments did not consistently increase with each incremental compost application (fig. 1). Differences in soil test P measurements among compost application rates are influenced by the non-uniform nature of the compost material and varying mineralization rates.

The following regression equation (r = 0.96), obtained from data collected on the no-hedge plots at the 0-5 cm soil sampling depth, relates WSP to Bray-1 P content:

$$\text{WSP} = 0.119(\text{Bray-1 P}) - 1.93 \qquad (1)$$

Equation 1 was derived using WSP values ranging from 1 to 49 mg kg^{-1} and Bray-1 P measurements varying from 26 to 407 mg kg^{-1}.

Soil Nitrogen

The content of NO_3-N and NH_4-N in the soil was significantly greater at the 0-5 cm soil sampling depth than at the 5-15 cm depth (table 1). The content of NO_3-N and NH_4-N averaged 26.2 and 5.8 mg kg^{-1} at the 0-5 cm depth, compared to 17.0 and 3.3 mg kg^{-1} at the 5-15 cm depth. Eghball et al. (2002a) found that long-term manure application increased NO_3-N levels in the top 0.1 m of the soil profile. The accumulation of NO_3-N in the upper soil profile can occur when manure or compost is applied to meet either annual or multi-year crop nutrient requirements (Eghball, 2002).

Measurements of NH_4-N were significantly greater on the no-hedge than the hedge treatments, averaging 6.4 and 2.8 mg kg^{-1}, respectively (table 1). Previous deposition of sediment may have increased the silt and clay sized soil fractions above the hedge, resulting in greater adsorption of NH_4-N by soil materials. No significant difference in soil NO_3-N content was found between the no-hedge and hedge treatments.

Significant differences in soil NO_3-N content was found among compost application rates (table 1). Differences in soil NO_3-N measurements among compost application rates are influenced by the non-uniform nature of the compost material and varying mineralization rates. Soil NH_4-N content was not significantly affected by compost application rate. Substantial nitrification of the NH_4-N contained in the compost appears to have occurred following land application, resulting in relatively small soil NH_4-N values at the time of testing.

RUNOFF CHARACTERISTICS

Runoff Phosphorus

The hedge × compost rate interaction was significant for DP (P = 0.01) and TP (P = 0.04) (table 2). Runoff losses of DP and TP were significantly greater on the no-hedge than the hedge treatments. When averaged across compost rates, 0.10 kg DP ha^{-1} and 0.18 kg TP ha^{-1} were measured in runoff from the hedge treatments, compared to 0.25 kg DP ha^{-1} and 0.56 kg TP ha^{-1} from the no-hedge treatments. Owino et al. (2006) measured nutrients in runoff from a clay loam soil in Kenya protected by narrow grass strips. The narrow strips of Napier grass reduced PO_4-P loss by 55% compared to similar sites without a grass strip.

Table 2. Effects of hedge and compost rate on the transport of dissolved P (DP), total P (TP), NO_3-N, NH_4-N, total N (TN), runoff, and erosion averaged over the three rainfall simulation runs.

Variable	DP (kg ha^{-1})	TP (kg ha^{-1})	NO_3-N (kg ha^{-1})	NH_4-N (kg ha^{-1})	TN (kg ha^{-1})	Runoff (mm)	Erosion (Mg ha^{-1})
Hedge							
Hedge	0.10	0.18	0.20	0.002	4.00	17	0.12
No-hedge	0.25	0.56	0.62	0.009	7.62	29	1.46
$LSD_{0.05}$	0.04	0.12	0.19	0.002	0.99	3	0.29
Compost rate (Mg ha^{-1})							
0	0.05	0.19	0.13	0.004	5.49	24	1.07
68	0.11	0.28	0.20	0.006	5.23	22	0.71
105	0.16	0.44	0.41	0.005	6.33	24	0.90
142	0.25	0.42	0.72	0.005	6.13	23	0.76
178	0.28	0.51	0.59	0.007	5.87	22	0.50
$LSD_{0.05}$	0.07	0.18	0.30				
ANOVA				Pr>F			
Hedge	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Compost rate	0.01	0.01	0.01	0.64	0.63	0.89	0.18
Hedge × compost rate	0.01	0.04	0.17	0.28	0.32	0.55	0.20

The 1.4 m wide narrow grass hedges used in the present study covered approximately 35% of the 4 m long plot area. As a result, nutrient transport would be expected to be less on the hedge treatments because of the smaller upslope contributing area. However, the reduction in loss of DP and TP in runoff from the hedge treatments was larger than the amount that could be attributed simply to a smaller upslope contributing area. Adsorption of nutrients by vegetation or soil materials within the hedge may have occurred. Since nutrient adsorption mechanics within the grass hedge system are not well defined, it is difficult to accurately estimate the effects of runoff contributing area on nutrient transport.

Significant differences in the transport of DP and TP were found among compost application rates (table 2). Runoff transport of DP from the no-hedge treatments consistently increased as the compost application rate became greater, varying from 0.06 to 0.48 kg ha^{-1} (fig. 2). The transport of DP in runoff was less on the hedge than the no-hedge treatments for each of the compost application rates.

Runoff transport of DP did not consistently increase with compost application rate on the hedge treatments (fig. 2). The compost used in the field tests was by nature non-homogeneous and would, therefore, be expected to have varying mineralization rates. The chemical and physical characteristics of the soil deposited above the hedge may also have resulted in varying runoff nutrient transport.

Regression equations were developed relating runoff transport of DP to Bray-1 P content of the soil at the 0-5 cm soil sampling depth (fig. 3). The range of Bray-1 P values was less on the hedge than the no-hedge treatments. The grass hedge was especially effective in reducing the transport of DP in runoff from sites with larger soil P values.

It is recognized that the correlation coefficient presented in figure 3 for the hedge condition is relatively small. The line representing the regression equation for the hedge condition was included to allow comparisons in DP transport with the no-hedge treatment. It is not recommended that the regression equation presented for the hedge condition be used for predictive purposes.

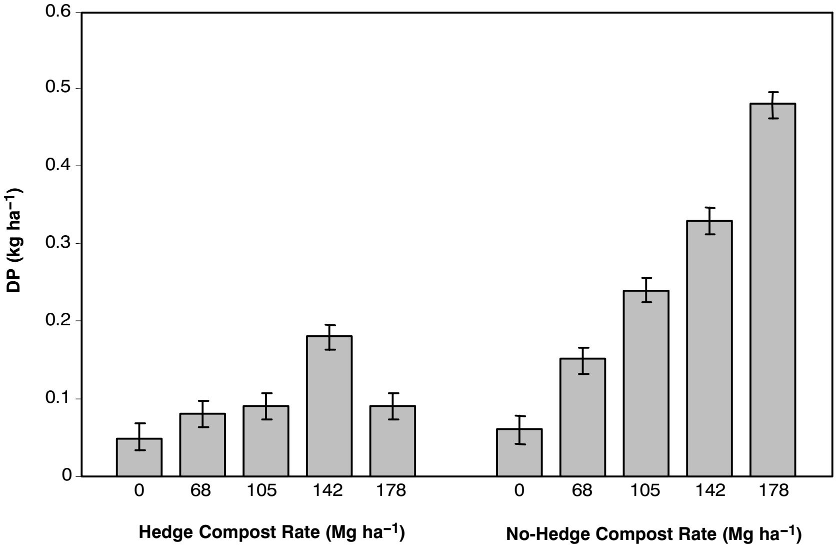

Figure 2. Transport of dissolved phosphorus (DP) in runoff as affected by compost application rate for the hedge and no-hedge condition. Nutrient transport values are averages from three rainfall simulation runs. Vertical bars are standard errors.

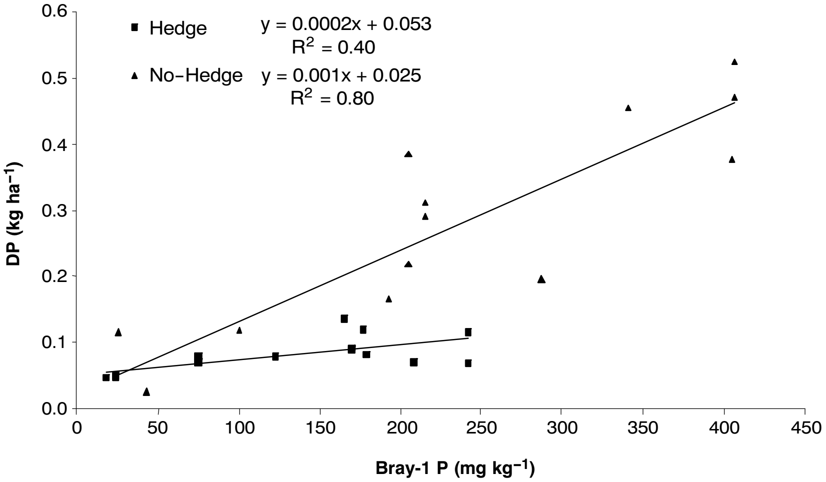

Figure 3. Transport of dissolved phosphorus (DP) in runoff as affected by Bray-1 P content of the soil for the hedge and no-hedge condition.

Runoff Nitrogen

The transport of NO_3-N, NH_4-N, and TN in runoff was significantly less on the hedge than the no-hedge treatments (table 2). When averaged across compost application rates, 0.20 kg NO_3-N ha^{-1}, 0.002 kg NH_4-N ha^{-1}, and 4.00 kg TN ha^{-1} were measured in runoff from the hedge treatments, compared to 0.62 kg NO_3-N ha^{-1}, 0.009 kg NH_4-N ha^{-1}, and 7.62 kg TN ha^{-1} from the no-hedge treatments.

Owino et al. (2006) measured nitrogen transport in runoff from a study site in Kenya on which a narrow strip of Napier grass was planted. The presence of the grass strip reduced the transport of NO_3-N and NH_4-N in runoff from a clay loam soil by 45% and 47%, respectively, compared to a similar site without a grass strip.

Significant differences in runoff transport of NO_3-N were found among compost application rates, with transport rates varying from 0.13 to 0.72 kg ha^{-1}. However, the transport of NH_4-N and TN in runoff was not affected by compost application rate.

Runoff and Erosion Measurements

Runoff was significantly less on the hedge than the no-hedge treatments, averaging 17 and 29 mm, respectively. Compost application rate did not significantly affect total runoff or erosion. Soil erosion was also significantly less on the hedge than the no-hedge treatments, averaging 0.12 and 1.46 Mg ha^{-1}.

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

RUNOFF CHARACTERISTICS AS AFFECTED BY INFLOW

The hedge × compost rate × inflow rate interaction was significant for TP ($P = 0.02$) and NO_3-N ($P = 0.01$) (table 3). Significant hedge × compost rate interactions were found for NO_3-N ($P = 0.01$) and NH_4-N ($P = 0.01$). The hedge × inflow rate interaction was significant for all of the runoff characteristics except NH_4-N ($P = 0.20$). Significant compost rate × inflow rate interactions were found for DP ($P = 0.01$), TP ($P = 0.01$), and NO_3-N ($P = 0.01$).

Phosphorus Measurements

The mean transport rate for DP was significantly less for the hedge than the no-hedge treatments, averaging 6.4 and 18.9 g ha^{-1} min^{-1}, respectively (table 3). Significant differences in the rate of DP transport occurred among compost application rates, with values ranging from 1.7 to 23.7 g ha^{-1} min^{-1}. The rate of transport of DP consistently increased with inflow rate, with transport values varying from 3.6 to 22.5 g ha^{-1} min^{-1}.

The 10.3 g ha^{-1} min^{-1} of TP transported in runoff from the hedge treatments was significantly less than the 47.3 g ha^{-1} min^{-1} measured on the no-hedge treatments (table 3). Compost application rate significantly affected the transport of TP in runoff, with rates varying from 6.9 to 50.2 g TP ha^{-1} min^{-1}. The runoff transport rate of TP consistently increased with inflow rate, with values varying from 8.7 to 52.8 g ha^{-1} min^{-1}.

Nitrogen Measurements

The transport rates of NO_3-N, NH_4-N, and TN in runoff were significantly less on the hedge than the no-hedge treatments (table 3). When averaged across compost rates, 23.6 g NO_3-N ha^{-1} min^{-1}, 0.15 g NH_4-N ha^{-1} min^{-1}, and 579 g TN ha^{-1} min^{-1} were measured in runoff from the hedge treatments, compared to 49.2 g NO_3-N ha^{-1} min^{-1}, 0.71 g NH_4-N ha^{-1} min^{-1}, and 840 g TN ha^{-1} min^{-1} from the no-hedge treatments.

Significant differences in transport rates of NO_3-N and NH_4-N were found among compost application rates. Transport rates varied from 15.3 to 69.0 g NO_3-N ha^{-1} min^{-1} and from 0.28 to 0.83 g NH_4-N ha^{-1} min^{-1}. The rate at which TN was transported in runoff was not significantly affected by compost application rate.

The transport rates for NO_3-N, NH_4-N, and TN in runoff varied significantly among inflow rates. Runoff transport rates ranged from 2.9 to 73.1 g ha^{-1} min^{-1} for NO_3-N, from 0.16 to 0.69 g ha^{-1} min^{-1} for NH_4-N, and from 171 to 1288 g ha^{-1} min^{-1} for TN. For a given runoff rate, the rate of transport of TN was less on the hedge than the no-hedge treatments (fig. 4).

Table 3. Runoff water quality parameters and soil loss as affected by hedge, compost rate, and inflow rate.

Variable	DP (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})	Soil Loss (kg ha^{-1} min^{-1})
Hedge						
Hedge	6.4	10.3	23.6	0.15	579	14.1
No-hedge	18.9	47.3	49.2	0.71	840	114.6
$LSD_{0.05}$	7.2	15.4	17.0	0.24	107	53.3
Compost rate (Mg ha^{-1})						
0	1.7	6.9	19.1	0.34	687	69.9
68	14.6	50.2	29.4	0.83	802	97.0
105	9.5	18.9	15.3	0.37	669	82.2
142	23.7	38.4	49.3	0.34	752	40.5
178	13.9	29.6	69.0	0.28	637	32.1
$LSD_{0.05}$	11.2	24.1	26.7	0.34		
Inflow rate						
Zero	3.6	8.7	2.9	0.16	171	29.0
One	6.6	15.5	18.0	0.31	371	24.8
Two	11.7	28.9	28.8	0.55	694	46.4
Three	19.1	37.9	59.5	0.69	1023	81.1
Four	22.5	52.8	73.1	0.46	1288	140.5
$LSD_{0.05}$	5.1	9.5	13.1	0.26	81	54.3
ANOVA						
Hedge	0.01	0.01	0.01	0.01	0.01	0.01
Compost rate	0.02	0.02	0.01	0.03	0.35	0.54
Inflow rate	0.01	0.01	0.01	0.01	0.01	0.01
Hedge × compost rate	0.21	0.07	0.01	0.01	0.75	0.61
Hedge × inflow rate	0.01	0.01	0.01	0.20	0.02	0.01
Compost rate × inflow rate	0.01	0.01	0.01	0.13	0.94	0.95
Hedge × compost rate × inflow rate	0.08	0.02	0.01	0.19	0.67	0.96

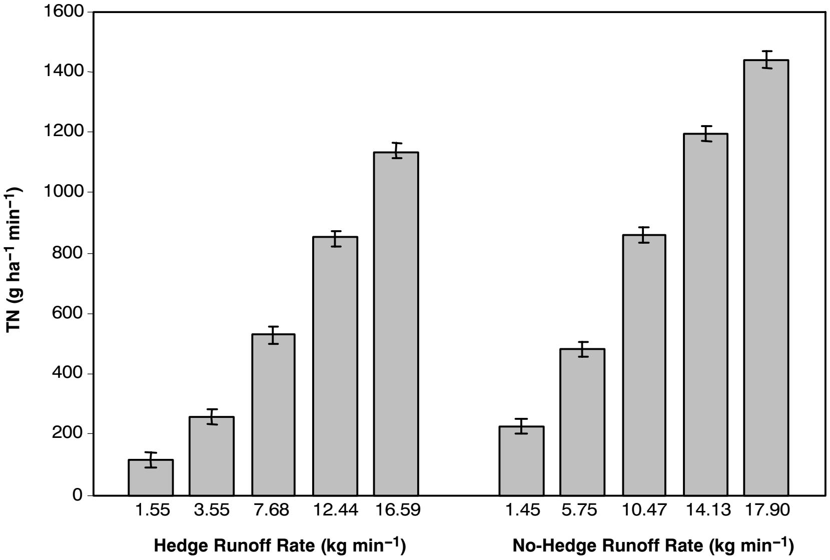

Figure 4. Transport of total nitrogen (TN) in runoff as affected by runoff rate for the hedge and no-hedge condition. Nutrient transport values were averaged across compost rates. Vertical bars are standard errors.

Soil Loss Measurements

Soil loss rate was significantly less on the hedge than the no-hedge treatments, averaging 14.1 and 115 kg ha^{-1} min^{-1}, respectively (table 3). Compost application rate did not significantly affect soil loss rates. Significant differences in soil loss rates were measured among inflow treatments, with values varying from 24.8 to 141 kg ha^{-1} min^{-1}. For a given runoff rate, soil loss measurements were greater on the no-hedge than the hedge treatments, especially for larger runoff values (fig. 5).

The increase in soil loss rate with flow rate is well established. Gilley et al. (1987) measured runoff rate, runoff velocity, sediment concentration, and soil loss rates at selected downslope distances on plots with varying rates of sorghum and soybean residue. Soil loss rate was found to increase with downslope distance.

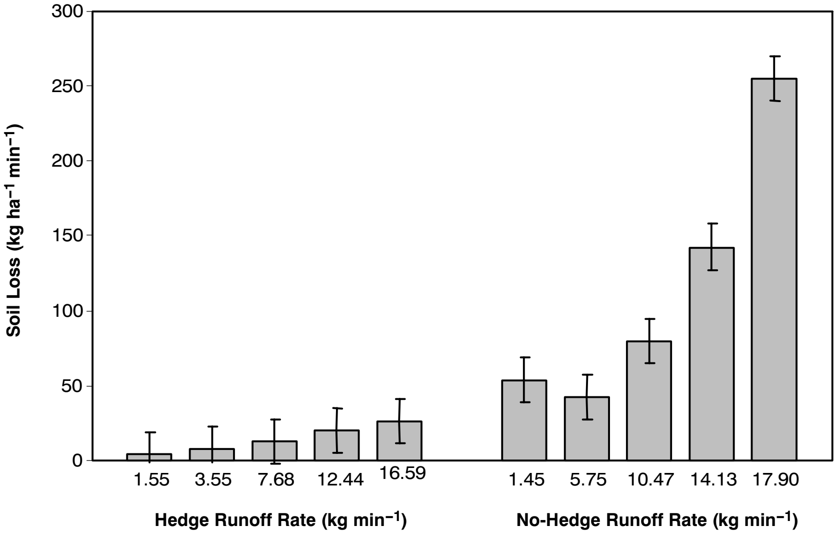

Figure 5. Soil loss as affected by runoff rate for the hedge and no-hedge condition. Soil loss values were averaged across compost rates. Vertical bars are standard errors.

THE USE OF NARROW GRASS HEDGES AS A BEST MANAGEMENT PRACTICE

Previous studies have shown that narrow grass hedges can effectively reduce runoff and soil loss from cropland areas. Results from this investigation suggest that narrow grass hedges can also decrease nutrient transport in runoff from soils containing excessive amounts of nutrients. The greatest reductions in runoff nutrient transport were found on those areas with the largest soil nutrient content.

Manure may be applied to meet annual or multi-year crop nutrient requirements. Land application costs can be reduced if manure is added at less frequent intervals. The use of stiff-stemmed grass hedges planted along the contour may be an effective best management practice on cropland areas that receive multi-year applications of manure.

The effectiveness of a single grass hedge in reducing nutrient transport by overland flow was examined in this study. Several stiff-stemmed grass hedges are usually planted along the contour from near the top to the bottom of the hillslope. Thus, several grass hedges may intercept overland flow as it moves downslope. Our experimental results indicate that nutrient transport increases with flow rate. A single grass hedge was able to effectively decrease nutrient transport in runoff for the flow rates examined in this study.

At present, the mechanisms responsible for reducing runoff nutrient transport have not been clearly identified. The stiff-stemmed grass hedges cause sediment to be deposited immediately above the hedge. The finer textured particles contained in previously deposited sediment may be able to absorb substantial amounts of nutrients. The slope gradients above a grass hedge may also be considerably less, increasing the length of time overland flow is in contact with the soil surface.

The vegetative materials within the grass hedge may also sorb nutrients contained in overland flow. The nutrient sorption capacity of grass hedges has not been identified. Removal of vegetative materials from the grass hedge area following harvest would reduce the accumulation of nutrients within the grass hedge system.

The use of stiff-stemmed grass hedges is only one of several best management practices available for reducing sediment and nutrient transport by 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. Stiff-stemmed grass hedges are best used as one part of a combination of soil and water conservation best management practices.

CONCLUSIONS

Stiff-stemmed grass hedges significantly reduced the transport of DP and TP in runoff. When averaged across compost application rates, the 0.20 kg NO_3-N ha^{-1} contained in runoff from the hedge treatment was significantly less than the 0.62 kg ha^{-1} measured from the no-hedge treatment. The stiff-stemmed grass hedge also decreased TN transport in runoff from 7.62 kg ha^{-1} on the no-hedge treatment to 4.00 kg ha^{-1} on the plots with a grass hedge.

The existence of a grass hedge, compost rate, and inflow rate all significantly influenced transport rates of DP, TP, NO_3-N, and NH_4-N on the treatments with added inflow. The 14.1 kg ha^{-1} min^{-1} of mean soil loss measured from the hedge treatment was significantly less than the 115 kg ha^{-1} min^{-1} obtained for the no-hedge condition. Differences in soil loss rates were found among inflow treatments, with values varying from 24.8 to 141 kg ha^{-1} min^{-1}.

Stiff-stemmed grass hedges could reduce the transport of nutrients in runoff from land application areas with a range of soil nutrient values. Runoff nutrient transport will significantly increase as overland flow rates become larger. A stiff-stemmed grass hedge effectively reduced nutrient and soil loss for the varying runoff rates used in this study.

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