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Narrow Grass Hedge Effects on Phosphorus and Nitrogen in Runoff Following Manure and Fertilizer Application

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Abbreviations: BAP, bioavailable phosphorus; DP, dissolved phosphorus; EC, electrical conductivity; PP, particulate phosphorus; TN, total nitrogen; TP, total phosphorus

ABSTRACT: Runoff losses of nitrogen (N) and phosphorus (P) from field applied manure can contribute to surface water pollution. Grass hedges may reduce runoff losses of nutrients and sediment. The objective of this study was to evaluate the effects of narrow switchgrass (Panicum virgatum L.) hedges (~0.75 m wide) on the transport of P and N from a field receiving beef cattle feedlot manure under tilled and no-till conditions. This study was conducted on a steep (12 % average slope) Monona silt loam (fine-silty, mixed, superactive, mesic Typic Hapludolls) soil near Treynor, Iowa. The experiment was a split-plot with no-till and disked systems as main plots and subplots of manure, fertilizer, and check with or without a grass hedge. A rainfall simulator was used and runoff was collected from both the initial and the following wet simulations. Only 38% of the no-till plots and 63% of disked plots had any runoff during the initial 6.4 cm hr^{-1} water application. A single narrow grass hedge reduced runoff concentrations of dissolved P (DP) by 47%, bioavailable P (BAP) by 48%, particulate P (PP) by 38%, total P (TP) by 40%, and NH_4-N by 60% during the wet simulation on the no-till plots receiving manure, compared with similar plots with no hedges. The corresponding reductions in concentrations as a result of a grass hedge for DP, BAP, PP, TP, and NH_4-N on the disked plots were 21, 29, 43, 38, and 52%, respectively. Runoff NH_4-N concentration from fertilizer applied to the disked plots was reduced by 61%, NO_3-N by 21%, and total N (TN) by 27% during the wet simulation when grass hedges were used. Grass hedges also reduced total quantities of DP, BAP, TP, and NH_4-N during the wet simulation. The TP loss was 3.3% of applied P fertilizer and was 0.3% of applied manure P. Narrow grass hedges were effective in reducing P and N losses in runoff from both manure and fertilizer application.

Keywords: Beef cattle manure, erosion, eutrophication, fertilizer, hypoxia, no-till, water quality

Environmental concerns must be addressed on areas receiving manure. Runoff from cropland areas receiving manure or fertilizer may contribute to increased P and N concentrations in streams and lakes. Even though P from manure application may move deep into the soil (Eghball et al. 1996), the primary concern about P pollution is with eutrophication of surface waters. The main factors controlling P movement in surface runoff are transport (runoff and erosion) and source factors such as manure or fertilizer application and soil P test level (Sharpley et al. 1993). Beef cattle feedlot manure applications less than 7 Mg dry weight ha^{-1} did not contribute significantly to P or N enrichment of surface waters on a field with 1% slope (Jones and Willis 1995). Mueller et al. (1984) found that application of 8 Mg ha^{-1} (dry weight) dairy manure resulted in significantly greater dissolved and bioavailable P loss in no-till as compared to a conventional tillage system. The bioavailable P loss followed the order: no-till > conventional = chisel. Eghball and Gilley (1999) showed that beef cattle feedlot manure or compost application based on N needs of corn *(Zea Mays L.)* resulted in significantly greater runoff concentrations of DP, BAP, PP, and TP than applications based on corn P needs in both the till and no-till systems.

Ammonium loss into surface waters can result in poisoning of aquatic organisms if the concentration is > 2.5 mg L^{-1} (USEPA 1986). Nitrate in runoff from fields receiving manure, compost, or fertilizer may be carried to rivers and lakes. The elevated nitrate concentration in the Gulf of Mexico may contribute to the extent of a hypoxia zone, which is depleted of oxygen (< 2 mg L^{-1}) and marine life (Turner et al. 1997).

Filter strips can substantially reduce P, N, and sediment in runoff from cultivated agricultural areas (Dillaha et al. 1989). Trapping efficiency for 4.57 m grass filter strips was > 90% for P, NO_3-N, NH_4-N, atrazine, and sediment and was even greater for wider grass strips (Barfield et al. 1998). Grass filter strips were also found to significantly trap fecal coliform in runoff from a soil receiving poultry manure (Coyne et al. 1995). Recently, narrow grass hedges planted on the contour along the hillslope, have been used as an effective conservation practice. As far as we know, no work has been conducted to evaluate the performance of narrow grass hedges for controlling P and N losses in runoff. The objective of this study was to determine the effects of narrow switchgrass *(Panicum virgatum L.)* hedges on the transport of P and N following a single application of manure under no-till and disked conditions.

Materials and Methods

This study was conducted during the summer of 1997 at the USDA-ARS Deep Loess Research Station approximately 19 km southeast of Council Bluffs, Iowa, on a Monona soil. The study site had been in continuous corn since 1964 and had been managed using spring tillage for seedbed preparation and weed control. In May 1991, switchgrass hedges were planted within a 6 ha watershed and they have grown to be approximately 0.75 m wide. The grass hedges were separated by 16 corn rows (97 cm row spacing). The average corn yield from 1987 to 1996 was 7.6 Mg ha^{-1} with average fertilizer applications of 146 kg N ha^{-1}, 12 kg P ha^{-1}, and 12 kg K ha^{-1}. There were no P and K applications two years prior to our experiment. Fertilizer application was made in early spring each year before tillage.

This study was conducted using a split plot in a randomized complete block design with three replications (36 total plots). The plots were located on the hillslope in between two grass hedges that were established along the approximate slope contour. Main plots consisted of no-till and disked conditions and subplots included manure (46.4 Mg dry weight ha^{-1}), inorganic fertilizer (151 kg N ha^{-1} and 25.8 kg P ha^{-1}), and check

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Table 1. Nitrogen and P concentrations and pH and EC of the soil in three experimental blocks.

	0-5 cm soil						5-15 cm soil					
Block	WSP†	BKP†	NO_3-N	NH_4-N	EC§	pH	WS P	BK P	NO_3-N	NH_4-N	EC	pH
	mg kg^{-1}				d S m^{-1}		mg kg^{-1}				d S m^{-1}	
1	1.03	100.9	3.55	5.72	0.33	5.9	4.41	55.4	3.49	7.19	0.22	4.8
2	2.25	70.5	2.71	8.27	0.26	5.6	3.47	42.1	1.89	6.55	0.19	4.7
3	3.90	77.2	3.10	5.28	0.25	5.1	0.78	26.9	2.46	5.22	0.23	5.1

† WSP is water soluble P and BKP is Bray and Kurtz No. 1.
§ EC is electrical conductivity. EC and pH were determined on 1:1 soil to water ratio.

plots without manure or fertilizer. Ammonium nitrate was the N source and the P source was granular diammonium phosphate (18-20-0, N-P-K). For each treatment, runoff was collected either above (a plot with no hedge) or below the grass hedges (another plot with hedge). The manure and fertilizer were surface applied by hand at the approximate rates required to meet N requirements for a corn crop with a target yield of 9.4 Mg ha^{-1}. Manure and fertilizer were disked immediately after application in the tilled treatment and were left on the soil surface in the no-till treatment.

The manure used in this study had a total N (TN) content of 8.2 g kg^{-1}, total P (TP) content of 5.5 g kg^{-1}, dissolved P (DP) of 550 mg kg^{-1}, NO_3-N of 47 mg kg^{-1}, and NH_4-N of 186 mg kg^{-1} on a dry weight basis. The manure had water content of 210 g kg^{-1}. It was assumed that the plant N availability from manure during the year of application was 40% based on the findings of Eghball and Power (1999). Nutrients contained in the applied manure included 378 kg N ha^{-1} and 256 kg P ha^{-1}.

A portable rainfall simulator based on a design by Swanson (1965) was used to apply rainfall simultaneously to two plots. Each 3.7 m wide by 10.7 m long plot was established using sheet metal borders. Weed control was achieved by herbicide application during the study period. The grass hedges were mowed to a height of approximately 45 cm prior to the rainfall simulation tests and they continued to grow throughout the study period. No vegetative density measurements were made. An initial one hour rainfall application at intensity of approximately 6.4 cm hr^{-1} was made at existing soil-water conditions. A second one hour application (wet simulation) was conducted approximately 24 hours later. Irrigation water had a NO_3-N concentration of 19 mg L^{-1}, a dissolved P concentration of 0.29 mg L^{-1}, and pH of 7.8. Soil characteristics of the experimental site are given in Table 1. The plots were covered with plastic between the initial and wet simulations to eliminate the input of natural rainfall into the system.

A trough extending across the bottom of each plot gathered runoff, which was measured using a flume with stage recorder. Runoff samples collected 5, 10, 15, 30, and 45 minutes after initiation of runoff from each plot were centrifuged, filtered, and analyzed for dissolved P (Murphy and Riley 1962), and NO_3-N and NH_4-N concentration using a Lachat (Zellweger Analytics, Milwaukee, WI) system. Non-centrifuged samples were analyzed for total P (Johnson and Ulrich 1959) and total N (Tate 1994) concentration, along with measurement of pH and electrical conductivity. Particulate P was calculated by the difference between total P and DP. Bioavailable P in runoff samples was measured using iron oxide-impregnated paper strips (Menon et al. 1990; Sharpley 1993). The total amount of each N or P component in runoff was determined by multiplying the concentration of that element by the amount of runoff for each respective sampling period.[1] For sediment content determination, runoff samples were collected from the trough at five minutes intervals from the initiation of runoff to 60 minutes. A stage recorder measured the rate and amount of runoff. The runoff samples were dried at 106°C and weighed to determine the solid materials.

Analysis of variance was used to determine differences between tillage systems and fertility treatments. Because there was runoff from only a few plots during the initial simulation, analysis of variance on concentration of P and N components and EC and pH was only performed for the wet simulation. For the initial simulation, the total amounts of each N or P component in runoff are reported. Because of non normality and large variability of the P and N parameters and EC and pH levels, these values were transformed using log (parameter + 10) (Steel and Torrie 1980). Analysis of variance was performed on the transformed data. In these analyses, time of runoff sampling was considered a subsample. A probability level ≤ 0.10 was considered significant.

Results and Discussion

The mean value of the slope at the study site was 12%. Residue cover ranged from 51% to 94% on the no-till treatments, and 11% to 58% on the disked plots. Mean corn residue cover for the no-till and disked treatments was 79% and 34%, respectively.

Analysis of variance indicated significant tillage by manure and fertilizer treatment interactions for all the parameters ($P < 0.02$ for all) except particulate P and pH during the wet simulation rainfall run. Therefore, the values for tillage and treatments are reported for all parameters in Table 2. For manure application to no-till plots, grass hedges (BH) reduced runoff concentration of DP by 47%, bioavailable P (BAP) by 48%, particulate P (PP) by 38%, TP by 40%, and NH_4-N by 60% when compared to similar plots without grass hedges (AH) (Table 2). For manure application under disked conditions, the corresponding reductions in runoff concentrations as a result of grass hedges were 21, 29, 43, 38 and 52% for DP, BAP, PP, TP, and NH_4-N, respectively.

Grass hedges reduced runoff concentration of BAP by 28% and NH_4-N by 39% on the no-till plots, and reduced TP by 22%, NO_3-N by 21%, and NH_4-N by 61% on the disked plots receiving chemical fertilizer, as compared with no hedges (Table 2). Most of the NO_3-N in runoff was from the irrigation water, which had an NO_3-N content of 19 mg L^{-1}. Grass hedges reduced runoff EC values in both tillage systems when manure was applied.

When grass hedges were used, manure application resulted in greater runoff DP

[1]For additional information regarding runoff and erosion measurements in this experiment, see Gilley et al. (2000).

Table 2. Effects of tillage and treatment on runoff concentrations of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate-N, ammonium-N, electrical conductivity (EC), and pH during the wet rainfall simulation.

Treatment	DP	BAP	Particulate P	Total P	NO_3-N[†]	NH_4-N	Total N	EC	pH
	mg L^{-1}							d S m^{-1}	
No-Till									
Check NH[#]	0.20 e[§]	0.80 e	3.9 b	4.1 cd	20.0 d	0.04 c	71.9 c	0.58 c	7.4 ab
Check WH	0.40 de	0.79 e	2.5 b	2.9 d	23.8 c	0.05 c	94.0 ab	0.53 d	7.3 ab
Fertilizer NH	0.96 c	1.65 c	4.1 b	5.1 bc	30.6 a	3.96 a	73.6 bc	0.61 bc	7.5 a
Fertilizer WH	0.71 cd	1.19 d	3.2 b	3.9 cd	31.2 a	2.42 b	100.3 a	0.60 bc	7.3 b
Manure NH	3.09 a	4.45 a	6.9 a	10.0 a	27.1 b	2.34 b	67.0 c	0.73 a	7.1 c
Manure WH	1.64 b	2.32 b	4.3 b	6.0 b	26.0 b	0.93 c	79.1 bc	0.62 b	7.0 c
Disked									
Check NH	0.17 c	0.75 c	4.5 ab	4.7 bc	18.5 c	0.33 d	51.4 d	0.60 bc	7.2 a
Check WH	0.36 c	0.75 c	2.1 d	2.5 d	19.6 c	0.03 d	43.7 d	0.57 c	7.1 a
Fertilizer NH	0.27 c	0.80 c	4.9 a	5.1 b	30.2 a	3.00 a	117.5 a	0.60 bc	7.2 a
Fertilizer WH	0.31 c	0.85 c	3.7 bc	4.0 c	23.9 b	1.16 c	85.4 b	0.53 d	7.2 a
Manure NH	1.42 a	2.35 a	4.9 a	6.3 a	26.8 b	2.35 b	60.4 cd	0.69 a	7.0 b
Manure WH	1.12 b	1.66 b	2.8 cd	3.9 c	25.6 b	1.13 c	79.6 bc	0.62 b	6.9 b

[†] Irrigation water had an average NO_3-N concentration of 19 mg L^{-1}.
[§] Within each tillage, the values are significantly different at 0.10 level if the same letter does not appear (Duncan's Test).
[#] WH and NH designate that the runoff samples were collected from plots with and without a grass hedge, respectively.

Table 3. Runoff concentrations of dissolved P (DP), bioavailable P (BAP), total and particulate P, and ammonium-N at different times during the wet rainfall simulation averaged across tillage and fertility treatments.

Time[†]	DP	BAP	Total P	Particulate P	NH_4-N
minute	mg L^{-1}				
0	0.44 b[§]	1.18 b	6.2 a	5.7 a	0.56 c
5	0.79 a	1.49 a	5.1 b	4.3 b	1.32 b
10	0.93 a	1.52 a	4.6 bc	3.6 bc	1.64 ab
15	0.95 a	1.53 a	4.3 bcd	3.3 bc	1.81 ab
30	0.97 a	1.49 a	3.6 d	2.6 c	1.97 a
45	0.50 b	0.98 b	3.4 d	2.9 c	1.95 a

[†] Time after runoff initiation.
[§] Within each column, the values are significantly different at 0.10 level if the same letter does not appear (Duncan's Test).

Table 4. Effects of tillage and treatment on the amounts of dissolved P (DP), bioavailable P (BAP), particulate and total P, nitrate-N, ammonium-N, and total N in runoff during the initial and wet rainfall simulations.

Treatment	DP	BAP	Particulate P	Total P	NO_3-N[†]	NH_4-N	Total N
	kg ha^{-1}						
Initial Simulation							
Tillage							
No-till	0.002 a[§]	0.003 a	0.010 a	0.016 a	0.052 a	0.002 b	0.239 a
Disked	0.010 a	0.020 a	0.089 a	0.173 a	0.604 a	0.033 a	1.868 a
Treatment							
Check NH[#]	0.003 a	0.007 a	0.109 a	0.111 a	0.473 a	0.006 b	1.074 a
Check WH	0.006 a	0.009 a	0.020 ab	0.025 a	0.284 ab	0.003 b	0.509 a
Fertilizer NH	0.007 a	0.019 a	0.088 ab	0.215 a	0.603 a	0.078 a	2.156 a
Fertilizer WH	0.001 a	0.002 a	0.007 b	0.124 a	0.030 b	0.001 b	1.171 a
Manure NH	0.013 a	0.022 a	0.040 ab	0.053 a	0.340 ab	0.014 b	0.646 a
Manure WH	0.005 a	0.010 a	0.033 ab	0.038 a	0.239 ab	0.003 b	0.764 a
Wet Simulation							
Tillage							
No-till	0.120 a	0.183 a	0.305 a	0.421 a	2.641 a	0.215 a	6.387 a
Disked	0.112 a	0.220 a	0.677 a	0.785 a	4.447 a	0.268 a	13.733 a
Treatment							
Check NH	0.039 b	0.133 b	0.691 ab	0.729 abc	3.333 b	0.027 d	11.772 ab
Check WH	0.036 b	0.074 b	0.217 b	0.253 c	2.220 b	0.005 d	5.832 b
Fertilizer NH	0.113 b	0.220 b	0.771 a	0.880 ab	5.504 a	0.696 a	16.777 a
Fertilizer WH	0.067 b	0.151 b	0.447 ab	0.501 abc	3.835 ab	0.279 bc	11.364 ab
Manure NH	0.305 a	0.448 a	0.592 ab	0.897 a	3.894 ab	0.324 b	7.159 b
Manure WH	0.135 b	0.181 b	0.229 b	0.357 bc	2.477 b	0.116 cd	7.456 b

[†] Irrigation water had an average NO_3-N concentration of 19 mg L^{-1}.
[§] Within each tillage or treatment for each simulation, the values are significantly different at 0.10 level if the same letter does not appear (Duncan's Test).
[#] WH and NH designate that the runoff samples were collected from plots with and without a grass hedge, respectively.

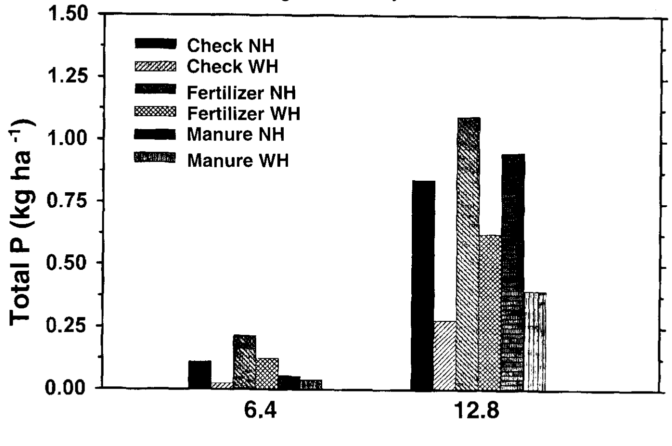

Figure 1. Total P in runoff for six treatments as influenced by water application.

Note: WH and NH designate that the runoff samples were collected from plots with and without a grass hedge, respectively.

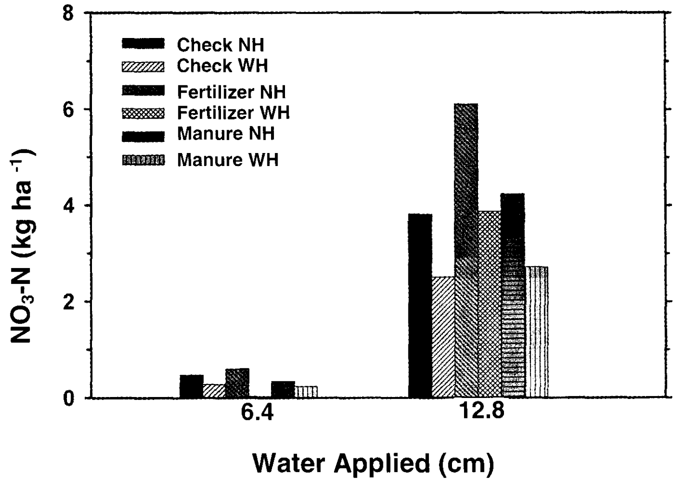

Figure 2. Nitrate-N in runoff for six treatments as influenced by water application.

Note: WH and NH designate that the runoff samples were collected from plots with and without a grass hedge, respectively.

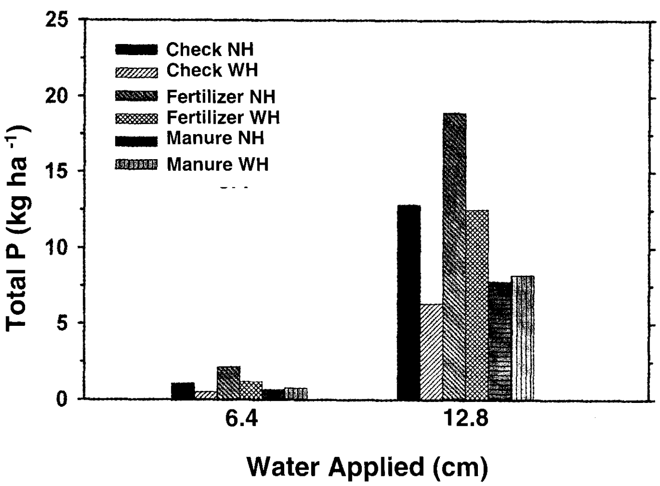

Figure 3. Total N in runoff for six treatments as influenced by water application.

Note: WH and NH designate that the runoff samples were collected from plots with and without a grass hedge, respectively.

and BAP concentrations than chemical fertilizer application under both tillage systems during the wet simulation (Table 2). When no-till plots had grass hedges, manure application resulted in lower runoff concentrations of NH_4-N, NO_3-N, and TN than chemical fertilizer application (Table 2). When grass hedges were not used, concentrations of all P components (except PP in disked treatment) were higher and N components were lower for manure than chemical fertilizer application in both tillage systems (Table 2).

Of the total amounts of fertilizer N and P applied, 3.3% of P and 10.4% of N was carried in runoff after 12.8 cm water application. Losses of applied manure N and P were 0.3 and 2.1% respectively, following 12.8 cm water application. Runoff EC values were higher for manure and fertilizer application on the no-till than the check plots, indicating greater runoff loss of salts from applied manure and fertilizer (Table 2). Runoff pH values were lower for manure than fertilizer or check plots indicating that possibly the organic acids in manure reduced runoff pH values (Table 2).

Ammonium-N concentration > 2.5 mg L^{-1} may be harmful to fish (USEPA 1973). Fertilizer application resulted in runoff NH_4-N concentrations > 2.5 mg L^{-1} on both tillage systems when grass hedges were not used (Table 2). When grass hedges were present, runoff NH_4-N concentrations were < than the critical 2.5 mg L^{-1} on both tillage systems. Manure application resulted in NH_4-N concentration < 2.5 mg L^{-1} on both tillage systems.

In some parts of the United States, a flow-weighted-annual DP runoff concentration of 1 mg L^{-1}, similar to that required of sewage treatment plants has been proposed for agricultural runoff (USEPA 1986). Manure application resulted in runoff DP concentrations > 1 mg L^{-1} in both tillage systems (Table 2). The DP concentrations were significantly reduced when grass hedges were used but were still near or above 1 mg L^{-1}. The runoff DP concentrations from fertilizer application were below the 1 mg L^{-1} in both tillage systems with or without grass hedges.

Effect of time after runoff initiation on P parameters and NH_4-N during the wet simulation is given in Table 3. Runoff concentrations of DP and BAP were lower at 0 and at 45 minutes than other times. Concentrations of PP and TP decreased with time while NH_4-N concentration was least for time 0 (Table 3).

Analysis of variance indicated no significant tillage by treatment interaction for the total amounts of P and N components in runoff. The main effect means of these parameters for tillage and treatments are given in Table 4. Total amounts of P and N components carried by runoff were not influenced by tillage system in either simulation except ammonium during the initial simulation (Table 4). The runoff N and P amounts were very low during the initial simulation because runoff occurred on only 6 out of 16 plots (up to 15 minutes runoff) on the no-till plots and 10 out of 16 (up to 30 minutes) for the disked plots. Grass hedges reduced total amounts of runoff NO_3-N and NH_4-N from fertilized plots during the initial simulation (Table 4). No effect of grass hedges was observed for the total quantities of the parameters on the plots receiving manure during the initial simulation.

Grass hedges reduced total amount of DP by 56%, BAP by 60%, TP by 60%, and NH_4-N by 64% on the manure plots during the wet simulation (Table 4). The TP loss in runoff was 33 g kg^{-1} of applied P fertilizer and was 3 g kg^{-1} of applied manure P. The TN loss in runoff was 104 g kg^{-1} of applied fertilizer N and 21 g kg^{-1} of applied manure N. The only parameter that was significantly influenced by grass hedges during the wet simulation on the plots receiving chemical fertilizer was NH_4-N quantity, which was reduced by 60%.

The amounts of total P, NO_3-N, and total N carried in runoff after application of 12.8 cm water are shown in Figures 1, 2, and 3, respectively. For all parameters, greater amounts were carried by 12.8 cm water application than 6.4 cm for all treatments.

Conclusions

Narrow grass hedges were effective in reducing the concentration and total amounts of P and N in runoff on this soil with an average slope of 12%. Grass hedges would potentially be more effective on soils with slope < 12%. The narrow grass hedges (< 1 m) were also found to reduce erosion under tilled conditions. Residue cover on the plots of this study eliminated runoff from 6.4 cm water application during the initial simulation in 63% of the no-till plots and in 38% of the tilled plots. Reside cover was 79% on the no-till and was 34% on the disked plots. The reductions in P and N concentrations and quantities in runoff as a result of using a single grass hedge were significant. More P was lost in runoff from the manured plots than from fertilizer plots. However, only 0.3% of applied manure P was lost in runoff as compared with 3.3% of applied fertilizer P. More N was lost in runoff from the fertilizer plots than the manure plots.

Grass hedges reduced runoff NH_4-N concentration to below the critical 2.5 mg L^{-1} from chemical fertilizer application in both tillage systems. Grass hedges significantly reduced runoff DP concentrations from applied manure in both tillage systems but the levels were still near or above the critical 1 mg L^{-1}. Runoff DP concentrations from applied fertilizer were < 1 mg L^{-1} in both tillage systems with or without grass hedges. Narrow grass hedges can be effective methods of reducing P and N losses in runoff from fertilized and manured fields under tilled and no-till management.

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