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Performance of Grass Barriers and Filter Strips under Interrill and Concentrated Flow

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ABSTRACT

Effectiveness of grass barriers and vegetative filter strips (FS) for reducing transport of sediment and nutrients in runoff may depend on runoff flow conditions. We assessed the performance of (1) switchgrass (*Panicum virgatum* L.) barriers (0.7 m) planted above fescue (*Festuca arundinacea* Schreb.) filter strips under interrill (B-FS) and concentrated flow (CF-B-FS), and (2) fescue alone under interrill (FS) and concentrated flow (CF-FS) for reducing runoff, sediment, nitrogen (N), and phosphorus (P) loss from fallow plots on a Mexico silt loam. We compared exclusively the performance of barriers and filter strips separately under interrill and concentrated flow. Runoff and sediment were sampled at 1 m above and at 0.7, 4, and 8 m below the downslope edge of the sediment source area. Filter strips under interrill flow reduced 80% and those under concentrated flow reduced 72% of sediment at 0.7 m ($P < 0.01$). With the addition of supplemental runoff simulating runoff from a larger sediment source area, FS reduced 80%, but CF-FS reduced only 60% of sediment. The FS reduced organic N and NO_3–N by an additional 50% ($P < 0.01$) more than CF-FS at 0.7 m. Although the effectiveness of both treatments increased with increasing width, CF-FS removed less sediment than FS alone at 8 m ($P < 0.04$). In contrast, barriers above filter strips under interrill and concentrated flow were equally effective at 8 m; decreasing runoff by 34%, sediment by 99%, and nutrients by 70%. Thus, barriers combined with FS can be an effective alternative to FS alone for sites where concentrated flows may occur.

Grass barriers and vegetative filter strips (FS) are conservation practices used to reduce nonpoint source (NPS) pollution in runoff. These practices differ in their design, vegetative species, and management (Daniels and Gilliam, 1996; Dabney et al., 1995; Dosskey et al., 2002; Blanco-Canqui et al., 2004a, 2004b). Grass barriers are hedges of stiff, perennial, and tall grass usually planted to warm season grass species in 0.75- to 1.2-m-wide strips (Kemper et al., 1992), whereas FS are wider strips of vegetation established between agricultural lands and streams and are often planted to fescue or other short-growing cool season grasses in 5- to 15-m-wide strips (Dillaha et al., 1989). Grass barriers are often established at short intervals (<15 m) in the field, paralleling rows of crops on the contour (Gilley et al., 2000). The FS, in contrast, are primarily grown along the bottom perimeter of fields.

While barriers and FS are effective for controlling transport of sediment and sediment-bound nutrients (Daniels and Gilliam, 1996; Eghball et al., 2000; Blanco-Canqui et al., 2004b), their performance depends on the runoff flow conditions (Dosskey et al., 2002). Studies suggest that FS are less effective in controlling NPS pollutant transport in concentrated runoff leaving large agricultural areas because they are prone to overtopping and inundation (Blanco-Canqui et al., 2004a). While there are questions on the effectiveness of FS in concentrated flow, actual quantitative field and plot data comparing FS performance under interrill and concentrated flow are limited. A review of FS research has highlighted the need for conducting field studies designed to assess the FS performance for reducing transport sediment and nutrients under concentrated runoff (Krutz et al., 2005).

Grass barriers may offer higher hydraulic resistance to concentrated runoff because of their stiff stems and upright growth (Dunn and Dabney, 1996; Blanco-Canqui et al., 2004b), but field and plot studies designed to document the performance of barriers under interrill and concentrated flow conditions are also few. A lab study by Meyer et al. (1995) showed that switchgrass barriers, planted across concentrated flow channels, ponded runoff up to 400 mm above the barriers, trapping ~90% of coarse sediments. A related lab study by Dabney et al. (1995) reported that barriers ponded concentrated runoff and deposited sediment above the barriers more than FS did. Gilley et al. (2000) showed that switchgrass barriers changed the surface hydrology of the soil by ponding runoff above barriers, thereby reducing interrill flow in croplands. Some studies have suggested that barriers may be more effective at trapping sediments than at reducing runoff (Self-Davis et al., 2003). In a field study, Dabney et al. (2004) observed that switchgrass barriers planted at 0.5-m intervals across concentrated flow channels showed potential for stabilizing gullies and reducing soil erosion in sloping lands. The potential of barriers for reducing runoff, sediment, and nutrient transport is partly attributed to the improved soil structure. Soils under long-term switchgrass barriers often have lower bulk density and higher macroporosity (Rachman et al., 2004a), and higher saturated hydraulic conductivity and water infiltration rates (Rachman et al., 2004b) which can reduce runoff (Gilley et al., 2000).

Blanco-Canqui et al. (2004a, 2004b) compared the effectiveness between barriers and FS for reducing sediment and nutrient transport in interrill and concentrated runoff. However, the authors did not assess the effectiveness of each conservation practice separately under interrill and concentrated flow. Field data on individual performance of barriers or FS are needed for proper design, use, and management. Data are also needed for the development and validation of models to predict

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Abbreviations: B-FS, grass barriers above filter strips; CF-B-FS, grass barriers above filter strips in concentrated flow; CF-FS, filter strips in concentrated flow; FS, filter strips; NPS, nonpoint source.

performance of barriers and FS for reducing transport of NPS pollutants (Srivastava et al., 1998; Krutz et al., 2005). The hypotheses of this study were that: (1) the FS are effective under interrill runoff, but their effectiveness in concentrated flow is significantly less, and (2) barriers remain equally effective under both interrill and concentrated flow. If these hypotheses hold, it would suggest that barriers may be used as a companion treatment to FS to enhance the effectiveness of FS to reduce concentrated runoff from agricultural fields, and reduce the amount of land usually required for FS establishment when they are used by themselves. Although barriers alone may remove significant amounts of sediment in runoff, wider buffers may be needed for effective removal and transformation of dissolved NPS pollutants (Dabney et al., 2006). We hypothesize that wider buffers consisting of FS accompanied by barriers above may be an alternative for reducing NPS pollution in concentrated runoff. The study objectives were to assess the effectiveness of (1) FS alone, and (2) switchgrass barriers planted above FS for reducing runoff, sediment, N, and P loss in interrill and concentrated flow conditions.

MATERIALS AND METHODS

Study Description

The study site was at the Bradford Research and Extension Center located 17 km east of Columbia, MO. The soil was a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) under perennial fescue grass (>10 yr) with a 4.9 ± 0.6% slope. Eighteen 1.5- by 16-m plots with six treatments replicated three times were established in a randomized complete block design. The six treatments were: (1) a fescue filter strip (FS), (2) a switchgrass barrier (the word *barrier* will be used to refer to switchgrass barrier in this paper) above a native species filter strip, (3) concentrated flow (CF) above a fescue filter strip with no barrier (CF-FS), (4) CF above a barrier combined with a fescue filter strip (CF-B-FS), (5) a switchgrass barrier combined with a fescue filters trip (B-FS), and (6) a check managed in continuous cultivated fallow without switchgrass barrier or filter strip.

This paper only evaluates four treatments including FS, CF-FS, CF-B-FS and B-FS because the objective of the study was to compare the performance between B-FS and CF-B-FS and between FS and CF-FS for reducing sediment and nutrient transport in interrill and concentrated flow. Data from all six treatments were, however, used in statistical analysis per the original design to improve the statistical power. This study was designed to compare the effectiveness of each conservation practice separately under interrill and concentrated flow. Information from this study would be useful to the design and management of these grass systems under the two types of runoff. Comparison of performance between B-FS and FS and between CF-B-FS and CF-FS were reported in a companion study (Blanco-Canqui et al., 2004b).

The plots were oriented up- and downslope along the dominant soil slope, and bordered with 200-mm-high by 250-mm-wide soil berms treated with polyacrylamide at a rate of 9 kg ha^{-1} and Du Pont nonwoven geotextile fabric (Blanco-Canqui et al., 2004c). Plots had an upslope 1.5- by 8-m pollutant source area managed under continuous cultivated fallow, above a downslope FS of equal size. The source area was tilled with a rototiller to a depth of ~80 mm in July 2001 and also rototilled after rainfall events. A 0.7-m barrier was established from mature transplants at the downslope edge of the source area just above a FS in July 2001. Existing fescue was used as FS in both treatments and periodically mowed to 100 mm high. A 200-mm-wide by 100-mm-deep v-shaped channel was constructed in the center of the pollutant source area of CF-FS and CF-B-FS to simulate concentrated flow.

Rainfall Simulation and Runoff Collection

A rotating-boom rainfall simulator was used to apply rainfall to assess the performance of the treatments (Swanson, 1965). The simulator was positioned between two plots and supplied rainfall to a plot pair at 66 ± 5 mm h^{-1}. A dry-run rainfall application of 1 h was applied 24 h before wet-run application of the same intensity and duration. The dry and wet rainfall applications were selected to match natural rainfall events with a 10-yr return period for mid-Missouri (Hershfield, 1961). Fertilizer was applied at 80 kg ha^{-1} of N, 35 kg ha^{-1} of P, and 66 kg ha^{-1} of K to the source area 24 h before rainfall. No crop was grown, and fertilizer was applied only to assess the treatment effectiveness for trapping nutrients.

V-shaped collectors (0.08 m wide, 1.5 m long, and 0.06 m deep) were constructed of angle iron to sample runoff water. They had a hinged cover fitted with a watertight gasket to close it to the V-shaped trough. Collectors could be opened and closed quickly between sampling periods because of the hinged covers. Collectors were installed perpendicular to the soil slope and across the plot width at 1 m above the downslope edge of the source area and in the FS area at 0.7, 4, and 8 m below the source area. A V-shaped groove was cut in the soil to place the collector. Collectors were tightly anchored with four steel spikes (10 mm diam. by 250 mm long) to eliminate runoff undercutting below. Collection pits of 300-mm diam. by 250-mm depth were sited just outside the plot area to place sampling containers. Collectors were set to a 3% slope of hydraulic head to facilitate water flow into containers in collection pits.

Runoff was sampled every 10 min. for 5 s at all sampling positions during the 1-h wet-runs. Samples were collected first from the collector at the lower end of the plot and then successively from each collector upslope (Chaubey et al., 1994) to prevent runoff flow from breaking downstream (Srivastava et al., 1996). Total runoff volume was regressed against time of collection, and the resulting regression equations were integrated over time from 0 to 60 min to compute runoff volume on a 1-h basis. Runoff depth was computed as the ratio of the runoff volume to the contributing area above a sampling point in accord with similar studies (Gilley et al., 2000).

Sediment, Nitrogen, and Phosphorus Analysis

Two aliquots of runoff were taken for the sediment, N, and P analyses. One 0.5-L aliquot was used for determination of sediment concentration. One composite 0.25-L aliquot for each sampling position over time was used for the N and P analysis. Runoff sediment concentration was measured by evaporation (Brakensiek et al., 1979). Samples for nutrient analysis were stored in an insulated cooler, transported to the laboratory, and immediately filtered through a Whatman #1 filter paper for determining nitrate (NO_3–N), ammonium (NH_4–N), and orthophosphate (PO_4–P) concentrations. Total N and P concentrations were determined from the unfiltered sample volumes. Analysis of N and P was conducted using a Lachat flow injection analyzer (Lachat QuikChem 800, Zellweger Analytics, Milwaukee, WI*)*. Sediment and nutrient masses were computed as the product of runoff and concentration (Eghball et al., 2000). Organic N was calculated as the difference between NO_3–N and NH_4–N from total N, whereas particulate P was the difference between total P and PO_4–P (Eghball et al., 2000). Runoff sediment was divided by the

Table 1. Mean (n = 3) runoff, sediment mass, and nutrient mass for the four treatments including fescue filter strip (FS), fescue filter strip under concentrated flow (CF-FS), switchgrass barrier above FS (B-FS), and B-FS under concentrated flow (CF-B-FS).

Parameter	Position	Treatments FS	CF-FS	B-FS	CF-B-FS	SD†
	m	mm				
Surface runoff	−1	57.3	62.8	55.3	61.1	2.9
	0.7	50.0	54.8	45.9	51.1	1.5
	4	45.4	46.5	40.5	45.1	2.3
	8	38.6	42.0	36.3	38.8	2.5
		$Mg\ ha^{-1}$				
Sediment	−1	10.2	13.15	10.8	13.59	1.7
	0.7	2.0	3.74	0.8	0.96	1.3
	4	0.7	1.23	0.4	0.39	0.4
	8	0.3	0.38	0.2	0.11	0.1
Nutrients		$kg\ ha^{-1}$				
Organic N	−1	4.73	4.94	4.50	5.00	0.29
	0.7	1.81	2.84	1.29	0.58	0.66
	4	0.89	0.85	0.94	0.20	0.59
	8	0.58	0.69	0.38	0.12	0.24
Particulate P	−1	2.10	2.31	2.00	2.28	0.20
	0.7	0.97	1.08	0.69	0.29	0.27
	4	0.40	0.31	0.32	0.24	0.19
	8	0.10	0.18	0.04	0.13	0.05
NO_3–N	−1	0.66	0.73	0.61	0.71	0.12
	0.7	0.43	0.58	0.16	0.44	0.28
	4	0.20	0.37	0.12	0.30	0.16
	8	0.11	0.27	0.07	0.19	0.02
NH_4–N	−1	1.90	2.02	1.97	1.98	0.19
	0.7	1.49	1.24	0.97	0.53	0.20
	4	0.56	0.57	0.39	0.37	0.08
	8	0.26	0.33	0.18	0.14	0.09
PO_4–P	−1	0.86	0.95	0.94	0.89	0.07
	0.7	0.49	0.27	0.37	0.16	0.13
	4	0.20	0.16	0.19	0.10	0.07
	8	0.12	0.12	0.09	0.05	0.04

† SD = Pooled standard deviation for the mean of the four treatments.

corresponding contributing area above a sampling point to compute sediment mass per unit area.

Addition of Inflow

Additional runoff inflow was added at the top of the plots to expand the assessment of the effectiveness of the treatments for controlling concentrated flow. Additional inflow simulated greater runoff that would be expected to occur from a larger sediment source area. Inflow was applied at 2.5, 5.0, 7.5, 10.0, and 12.5 L min^{-1} to simulate sediment source areas of 1.2, 1.4, 1.6, 1.8, and 2 times (1.2×, 1.4×, 1.6×, 1.8×, and 2×) the actual plot size. Inflow was added simultaneously with 62.5 ± 5 mm h^{-1} of simulated rainfall by pumping from a 3.7-kL polyethylene tank coupled with flow rate regulators (Omega FP-5300, Eng., Stamford, CT). Inflow entered plots through a 1.5-m-wide, 80-mm-i.d. pipe placed on the contour across the plot width. The pipe had 10-mm-diam. holes at 50-mm intervals on the downslope side to deliver water onto a 0.15- by 1.5-m piece of geotextile fabric used to reduce scour erosion. Inflow was started 10 min after the initiation of simulated rain and continued throughout the duration of rainfall. Inflow was applied for a period of 15 min after which runoff samples were collected for that inflow. The inflow rate was then increased to the next higher rate, and the process of sampling was repeated. Runoff weight was measured by location, and aliquots were taken only for measurement of sediment concentrations. Runoff and sediment mass were integrated over time for a total of 15 min of simulation.

Statistics

The General Linear Models (GLM) procedure of SAS (SAS Institute, 2005) was used to conduct the analysis of variance (ANOVA) to test the hypotheses that differences in runoff, sediment, and nutrient reduction between adjacent sampling positions (−1 and 0.7, 0.7 and 4, and 4 and 8 m) were the same for interrill and concentrated flow conditions. Orthogonal contrasts were used to test the main effects for FS, CF-FS, CF-B-FS, and B-FS. The percent values of runoff, sediment, or nutrient were computed using Eq. [1]

$$\% = \left(\frac{A_i - A_1}{A_i}\right) \times 100 \qquad [1]$$

where A_i is the amount of runoff, sediment or nutrient collected at −1 m sampling position above the downslope end of the source area and A_1 is the amount of runoff, sediment or nutrient leaving each sampling position (0.7, 4, 8 m).

RESULTS AND DISCUSSION

Performance of Fescue Filter Strips under Interrill and Concentrated Flow

Runoff and Sediment

Mean runoff depth, sediment mass, and nutrient mass by sampling position (0.7, 4, and 8 m) are shown in Table 1. Differences in runoff reduction between FS and CF-FS were not significant, indicating that filter strip performance for reducing runoff was not affected by runoff flow conditions (Table 2). On the average, both treatments reduced runoff by 13% at 0.7 m and

Table 2. Statistical significance of differences in runoff, sediment, and nutrients for three widths (0.7, 4, and 8 m) of switchgrass barriers planted above fescue filter strips under interrill (B-FS) and concentrated flow (CF-B-FS), and fescue alone under interrill (FS) and concentrated flow (CF-FS).

Source	df	Runoff	Sediment	Organic N	NO_3–N	NH_4–N	Particulate P	PO_4–P
		$P < F$						
		Contrast of differences between 1 m above and 0.7 m						
FS vs. CF-FS	1	ns	0.01**	0.01**	0.01**	ns	0.01**	ns
B-FS vs. CF-B-FS	1	ns	ns	ns	ns	ns	ns	ns
		Contrast of differences between 0.7 and 4 m						
FS vs. CF-FS	1	ns	0.03*	0.04*	ns	ns	0.03*	ns
B-FS vs. CF-B-FS	1	ns	ns	ns	ns	ns	ns	ns
		Contrast of differences between 4 and 8 m						
FS vs. CF-FS	1	ns	0.04*†	0.04*	ns	ns	0.04*	ns
B-FS vs. CF-B-FS	1	ns	ns	ns	ns	ns	ns	ns

*,** Significant at the 0.05 and 0.01 probability levels, respectively.
† Significant only between FS and CF-FS with additional inflow.

by 33% at 8 m, indicating that reduction in runoff increased with treatment width. Similar work showed that filter strips can reduce between 10 (Chaubey et al., 1994) and 90% (Schmitt et al., 1999) of runoff depending on the runoff flow type (Dabney et al., 1995), soil slope (Dillaha et al., 1989), FS type (Lee et al., 2003), and FS width (Srivastava et al., 1996). The relatively small reduction in runoff in this study may be due to a high rainfall intensity (66 ± 5 mm h^{-1}) and bare fallow source area that reduced water infiltration.

Performance of FS during interrill and concentrated flow relative to reducing sediment transport was significantly affected by runoff flow conditions. The CF-FS treatment was less effective in reducing sediment transport than the FS treatment ($P < 0.01$) at all sampling positions (Table 2). At 0.7 m, the FS reduced 80% of sediment leaving the source area, but the CF-FS reduced only 72%. When the sediment source area was effectively doubled by addition of supplemental runoff, the CF-FS only reduced 60% of sediment mass ($P < 0.05$; Fig. 1A). The FS reduced 93% of sediment transport at the 4 m and 98% at the 8 m position, but the CF-FS reduced 87 and 94% at the same positions ($P < 0.05$). Differences in sediment reduction between FS and CF-FS with additional inflow at the 4- and 8-m positions were much smaller than those at the 0.7-m position, indicating that the effectiveness of filter strips increases with distance in accord with similar studies (Dillaha et al., 1989).

Our results show that the performance of narrow FS for reducing sediment transport in runoff decreased significantly as the runoff became concentrated. Results support the recommendation that narrow FS should not be used in concentrated flow areas as suggested by Dillaha et al. (1989). Increase in FS width from 0.7 m to 8 m increased sediment reduction, but this reduction for CF-FS with additional inflow was still lower (about 4%) than for FS at 8 m ($P < 0.04$), indicating that increases in runoff concentration reduce the effectiveness of filter strips in spite of increases in filter strip width. Daniels and Gilliam (1996) stated that dispersion of concentrated runoff before it enters the FS may enhance performance of narrow FS.

The lower effectiveness of CF-FS was attributed to the bending of grass stems by concentrated runoff and channelization of flow near the edge of the sediment source area. The filtering capacity of the CF-FS treatment declined with increased transport capacity of the concentrated runoff. We observed that the upper 1-m CF-FS adjoining the field edge was partially inundated with runoff at the end of 1 h of rain simulation with supplemental runoff. We hypothesize that the lower effectiveness of the CF-FS is related to the reduction in hydraulic roughness and stiffness of the fescue stems. It is conceivable that concentrated runoff velocity in CF-FS was higher through the filter strips, reducing settling and infiltration of fine sediments when compared to interrill flow in FS.

Nitrogen and Phosphorus

Nutrient reductions between FS and CF-FS were variable. The FS removed organic N (Fig. 1B) and NO_3–N

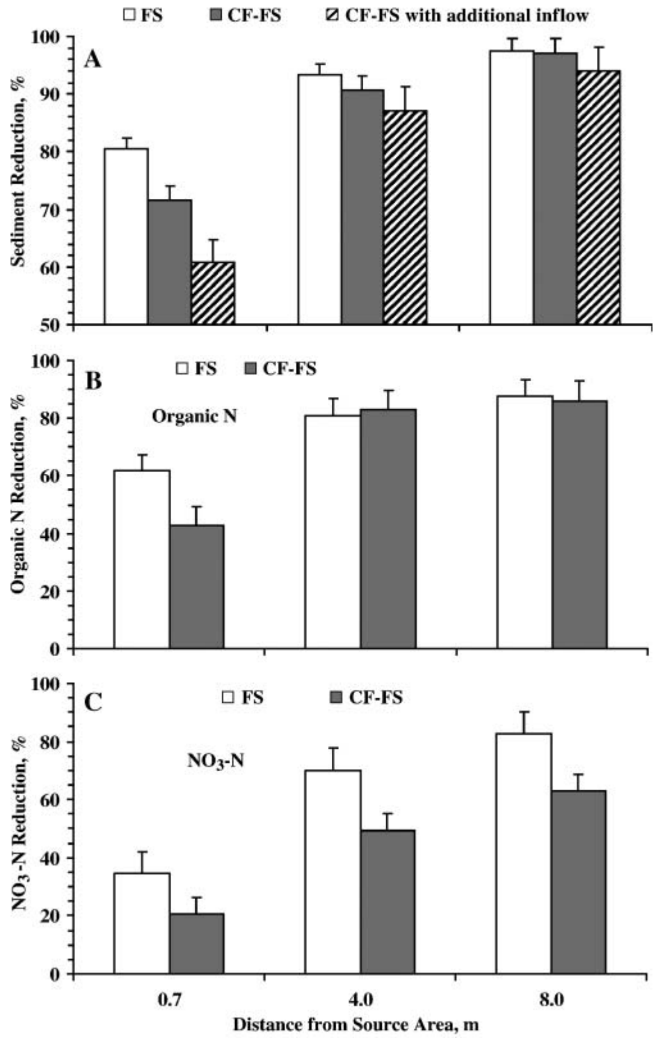

Fig. 1. Reduction in (A) sediment mass, (B) organic N, and (C) NO_3–N by distance from source area (0.7, 4, and 8 m) in (A) fescue filter strips under interrill flow (FS) and fescue filter strips under concentrated flow (CF-FS). Error bars represent the standard deviation of the mean ($s/\sqrt{n}$). Because there were no significant differences in sediment and nutrient reduction between interrill and concentrated flow within grass barriers, graphs were not depicted for the corresponding treatments.

(Fig. 1C) more than CF-FS at the 0.7-m position ($P < 0.01$), but differences in other nutrients were not significant. The FS removed 62% of organic N and 34% of NO_3–N, whereas the CF-FS removed only 43% of organic N and 21% of NO_3–N. On average, the 0.7-m FS and CF-FS removed 54% of particulate P, 30% of NH_4–N, and 58% of PO_4–P (Table 1). As with sediment, results showed that the effectiveness of narrow FS for removing organic N and NO_3–N was significantly reduced with concentrated runoff. The low effectiveness of FS under concentrated flow for removing organic N mirrored the low sediment reduction for this treatment. Sediment removal was correlated to organic N ($r^2 = 0.98$; $P < 0.01$). It was somewhat surprising that differences in P removal between FS and CF-FS were not significant. One might expect that the higher sediment reduction by FS may also result in higher reduction of particulate P as with organic N. High variability in data may have diminished differences in sediment P between the FS and CF-FS. Removal of particulate P rapidly increased, however, with an increase in treatment width.

Reduction in N loss increased with treatment width for both flow conditions, and nutrient removal between FS and CF-FS did not differ at the 4- and 8-m positions except for NO_3–N ($P < 0.05$). The 4-m strip removed 70% of NO_3–N under interrill and 49% under concentrated flow, whereas the 8-m strip removed 83% under interrill and 63% under concentrated flow. Greater filtering of sediments and improved infiltration may be the reasons for the higher reduction of NO_3–N in FS (Daniels and Gilliam, 1996). Results suggest that concentrated runoff leaving fields with little or no vegetative and/or residue cover diminishes the effectiveness of narrow FS for controlling losses of organic N and NO_3–N.

Performance of Grass Barriers with Filter Strips in Interrill and Concentrated Flow

Runoff and Sediment

Differences in runoff and sediment reduction between B-FS and CF-B-FS were not significant at any sampling position ($P > 0.10$; Table 2). Both B-FS and CF-B-FS reduced 17% of runoff at the 0.7-m and 34% at the 8-m sampling positions. They reduced an average of 92% of sediment transport at 0.7 m (Table 1). The addition of supplemental inflow did not significantly decrease the performance of barriers. Reduction of sediment transport increased with distance. About 97% was trapped at the 4-m and 99% at the 8-m position, showing that the greatest sediment reduction occurred in the 0.7 m. The B-FS and CF-B-FS spread runoff and created temporary ponding of runoff above the barriers, thereby inducing sediment deposition and thus minimizing sediment in downstream runoff. Runoff ponding depth was 20% more and occupied 25% more area extending above the barriers, forming a larger delta. Barriers did not fail for the conditions of this study.

Based on these results, barriers combined with FS offer a promise for reducing offsite movement of sediment in concentrated runoff. Results agreed with those of Rey (2004) who reported that vegetative barriers can be effective for reducing sediment losses from highly eroded environments with steep slopes. Runoff dispersion by barriers can reduce the runoff energy and velocity to transport sediment in accord with Dabney et al. (2004), who observed that barriers do not only reduce gully erosion but also stabilize field gullies. Our results show that barriers planted immediately above FS can improve the performance of FS and prevent them from being overtopped with sediment-loaded runoff.

Combinations of various plant species for sediment and nutrient control has been shown as a potential and innovative soil erosion control practice (Sheridan et al., 1999). Grass species within mixtures interact and often increase infiltration and macroporosity better than single species.

Nitrogen and Phosphorus

No significant differences in nutrient removal between the B-FS and CF-B-FS treatments were found for any width (Table 2). The 0.7 m of B-FS and CF-B-FS treatment was highly effective, removing >50% of runoff nutrients measured at the edge of the source area. On the average, 70% of organic N, 54% of NO_3–N, 50% of NH_4–N, 65% of particulate P, and 60% of PO_4–P were removed by 0.7 m of buffer. At 8 m, B-FS removed 92% of organic N, 98% of particulate P, 89% of NO_3–N, 91% of NH_4–N, and 90% of PO_4–P, whereas CF-B-FS removed 92% of organic N, 94% of particulate P, 73% of NO_3–N, 91% of NH_4–N, and 89% of PO_4–P. These results indicated that within the scope of our study, barriers in conjunction with filter strips remained equally effective for reducing transport of nutrients under both interrill and concentrated flow conditions. The reduction of nutrient transport increased with distance.

CONCLUSIONS

This study assessed the performance of FS and grass barriers planted above FS for reducing transport of NPS pollutants in interrill and concentrated runoff for each conservation practice separately on a moderately eroded Mexico silt loam. Results showed that the effectiveness of 0.7 m FS alone was reduced from 25% to 10% for reducing sediment, from 62% to 43% for reducing organic N, and from 34% to 21% for reducing NO_3–N when interrill flow became concentrated flow. Thus, narrow FS are well suited to filter sediment and remove nutrients for interrill flow, but their performance for concentrated flow may be diminished under heavy rainfall, even in soils with gentle slopes (<5%).

Conversely, 0.7 m grass barriers with FS are effective for controlling soil (>90%) and nutrient (>50%) losses under both interrill and concentrated flow conditions. Increased effectiveness of barriers suggests that barriers can be used as a companion treatment to FS for reducing transport of NPS pollutants from agricultural fields. Increase in FS width from 0.7 m to 8 m increased significantly the performance of FS under concentrated flow. The sediment reduction under concentrated flow was only 3% lower than under interrill flow, implying that wide FS may be needed to significantly control the transport of NPS pollutants in concentrated flow although this measure would increase the land taken out of active production. The 0.7 m of barriers in conjunction with FS removed 92% of sediment whereas FS alone of the same width removed only 60% under concentrated flow, which suggested that a combination of 0.7-m barriers with FS may be a potential alternative to minimize the loss of production land for the establishment of wide FS for concentrated flow control.

It is important to mention that caution should be exercised when transferring the study results to field conditions. Performance of barriers under on-farm conditions may differ from that for plot settings. Larger rainfall storms (>65 mm h^{-1}) and higher concentrations of incoming runoff mingled with steeper soil slopes than those tested in this study will eventually cause the failure of grass barriers. The performance of barriers with FS is expected to depend on storm intensity, field slope, and management of the source area. Determination of threshold levels of the performance of grass barriers combined with FS for reducing concentrated flow under on-farm conditions is a research priority for large-scale use of these erosion control practices.

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