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Sediment and nutrient removal in an established multi-species riparian buffer

K.H. Lee, T.M. Isenhart, and R.C. Schultz

ABSTRACT: Riparian buffers are widely recommended as a tool for removing nonpoint source pollutants from agricultural areas especially those carried by surface runoff. A field plot study was conducted to determine the effectiveness of an established multi-species buffer in trapping sediment, nitrogen, and phosphorus from cropland runoff during natural rainfall events. Triplicate plots were installed in a previously established buffer with a 4.1 by 22.1 m (14 x 73 ft.) cropland source area paired with either no buffer, a 7.1 m (23 ft) switchgrass (*Panicum virgatum* L. cv. Cave-n-Rock) buffer, or a 16.3 m (53.5 ft) switchgrass/woody buffer (7.1 m swithgrass/9.2 m woody) located at the lower end of each plot. The switchgrass buffer removed 95% of the sediment, 80% of the total-nitrogen (N), 62% of the nitrate-nitrogen (NO_3-N), 78% of the total-phosphorus (P), and 58% of the phosphate-phosphorus (PO_4-P). The switchgrass/woody buffer removed 97% of the sediment, 94% of the total-N, 85% of the NO_3-N, 91% of the total-P, and 80% of the PO_4-P in the runoff. There was a significant negative correlation between the trapping effectiveness of the buffers and the intensity and total rainfall of individual storms. While the 7 m (23 ft) switchgrass buffer was effective in removing sediment and sediment-bound nutrients, the added width of the 16.3 m (53.5 ft) switchgrass/woody buffer increased the removal efficiency of soluble nutrients by over 20%. Similar or even greater reductions might have been found if the 16.3 m (53.5 ft) buffer had been planted completely to native warm-season grasses. In this buffer, combinations of the dense, stiff, native warm-season grass and woody vegetation improved the removal effectiveness for the nonpoint source pollutants from agricultural areas.

Keywords: Erosion, grass filter, nonpoint source pollution, riparian buffers, water quality

Nonpoint source (NPS) pollution is one of the most critical problems threatening the nation's water resources, and agriculture accounts for up to two-thirds of this pollution (Long, 1991). Accordingly, various types of best management practices (BMP's) have been developed to reduce the movement of pollutants from agricultural areas. Whereas on-site BMP's reduce pollutant transport from agricultural sources in many cases, they are not adequate to meet national water quality goals in other situations (Clausen and Means, 1989).

Riparian buffers are being used as BMP's to reduce the transport of NPS pollutants in agricultural runoff before they enter surface waters. Riparian vegetation facilitates the removal of suspended sediments and associated nutrient content from surface runoff (Peterjohn and Correll, 1984; Lowrance et al., 1988). The friction of the soil surfaces can reduce the velocity of runoff that consequently results in the sedimentation of particles, but riparian buffer vegetation and the layer of organic litter on the soil surface are much more effective in slowing the velocity of the surface runoff (Correll, 1997). Whereas the exact role and effectiveness of the various types of buffer vegetation are uncertain, dense stiff grasses are generally considered more effective in trapping particles in surface runoff than most other types of vegetation (Dabney et al., 1993; Meyer et al., 1995). Dabney et al. (1993) demonstrated that as little as a 12 cm (4.7 in) wide strip of switchgrass (*Panicum virgatum* L.) can dam water as high as 10 cm (3.9 in) deep. Buffer designs that use these stiff-stemmed grasses at their edge can slow surface runoff enough to cause large particles to settle out before entering the buffer. Further filtration by buffer vegetation and surface litter is significant only with large particles and aggregates (Dillaha and Inamdar, 1997). Buffer vegetation, including woody plants, may be effective in removing soluble nutrients from surface runoff by improved infiltration into the buffer soil (Vought et al., 1994). Infiltration is one of the most significant mechanisms influencing buffer performance. Not only does it provide the pathway for water and soluble chemicals to enter the profile but suspended fine soil particles with adsorbed chemicals also enter the profile thus decreasing not only surface runoff, but also sediment transport capacity. While the potential exists for some soil pores to plug, the high infiltration rates in buffer soils (Lee et al., 1999) and the dynamic nature of soil structure (Marquez et al., 1999) assures continued high infiltration. This assumes that the large particles in surface runoff are deposited before entering the buffer or shortly thereafter.

The beneficial environmental effects of riparian buffers has led to development of two national standards by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) for reduction of agricultural NPS pollution. One of these is the filter strip conservation standard or Code 393 and the other the riparian forest buffer standard or Code 391 (USDA-NRCS, 1999a and b). The national standards can be modified by each state NRCS office to fit local conditions. The riparian forest buffer conservation standard in Iowa consists of two distinct functional zones. Zone 1 begins at the upper edge of the active channel and extends a minimum distance of 12 m (40 ft) or at least one-third the total width of the buffer, with trees and/or shrubs suited to the site and the intended purpose. Zone 2 begins at the up-gradient edge of Zone 1 and extends 6 m to 36.6 m (20 to 120 ft) perpendicular to Zone 1. Native warm season grasses, with or without native forbs, are recommended for vegetation of Zone 2 (USDA-NRCS, 1999b). While the riparian forest buffer standard is believed to

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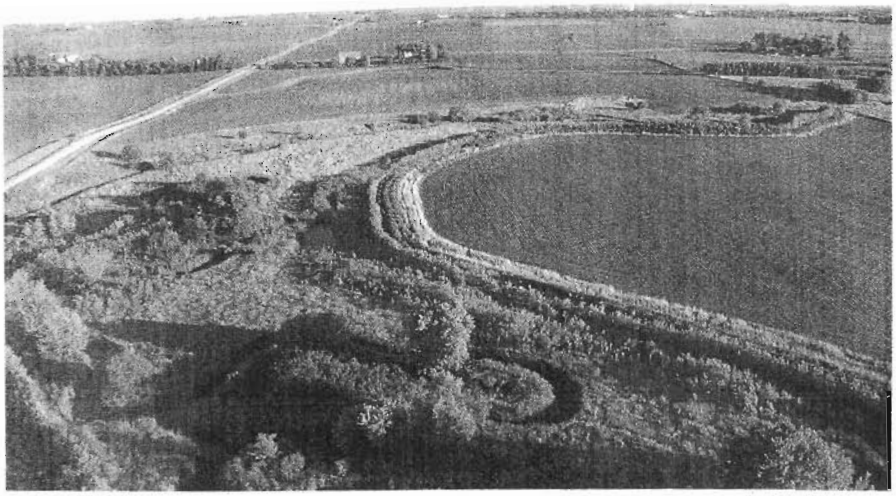
provide effective reduction of NPS pollution, there is little quantitative information on its effectiveness for reducing runoff, sediment, and nutrient movement. Such information is needed to modify buffer design and create credibility to improve landowner adoption.

The objectives of this study were to determine the effectiveness of an established switchgrass filter and a switchgrass/woody buffer in reducing runoff, sediment, nitrogen (N), and phosphorus (P) from corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] fields during natural rainfall events. These buffers were sized to conform to the Code 393 grass filter and the Code 391 riparian forest buffer standards (USDA-NRCS, 1999a and b).

Figure 1
Farm in Story County, Iowa where the experiment was conducted.

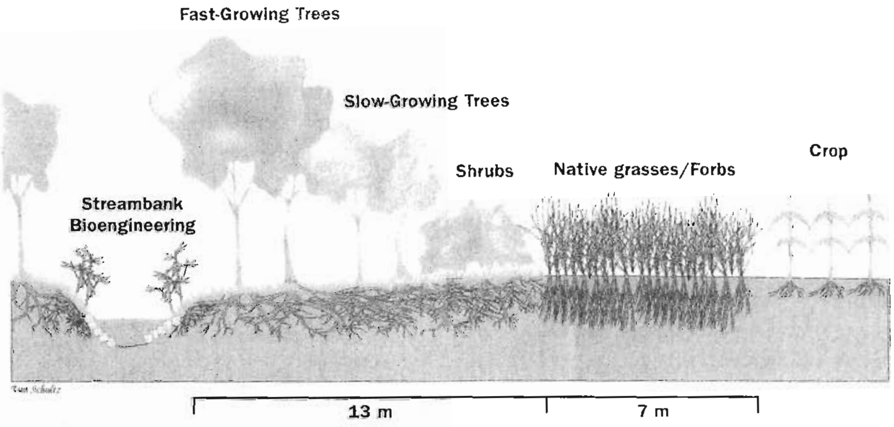


Methods and Materials

Site description. This study was conducted from May 1997 to November 1998 in a multi-species riparian buffer established in the spring of 1994 on a private farm along Bear Creek, in Story County, Iowa, USA (42°11'N, 93°30'W) (Figure 1). The multi-species riparian buffer consisted of a 7 m (23 ft) wide zone of switchgrass (*Panicum virgatum* L. cv. Cave-in-Rock) (Zone 2) adjacent to the cropland (Figure 2). This multi-species riparian buffer was used as a model for the development of the NRCS riparian forest buffer conservation standard. The 13 m (43 ft) wide woody plant zone consisted of shrubs and trees. Two rows of shrubs at 1.8 m (6 ft) spacing between rows and 0.9 m (3 ft) between plants within rows were installed. Shrub species included chokecherry (*Prunus virginiana* L.), Nanking cherry (*Prunus tomentosa* Thunb.), wild plum (*Prunus americana* Marsh.), red osier dogwood (*Cornus stolonifera* Michx.), and ninebark (*Physocarpus opulifolius* Max.). The four rows of trees were installed downslope of the shrubs with 2.4 m (8 ft) spacing between rows and 1.8 m (6 ft) between plants within rows. Tree species included silver maple (*Acer saccharinum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), black walnut (*Juglans nigra* L.), willow (*Salix* spp), cottonwood hybrids (*Populus* spp., e.g., *Populus* clone NC-5326, a designated clone of the North Central Forest Experiment Station), red oak (*Quercus rubra* L.), bur oak (*Quercus macrocarpa* Michx.), and swamp white oak (*Quercus bicolor* Willd.). Details of the multi-species riparian buffer design, placement, and plant species are given in Schultz et al. (1995). The soil under the multi-species riparian buffer was a Coland (fine-loamy, mixed, mesic cumulic Haplaquoll), with an average natural slope of 5%. Soil of the adjacent crop field source area was a Clarion (fine-loamy, mixed, mesic typic Hapludoll) with an average slope of 8% (Dewitt, 1984). The cropland source area was managed under a soybean [*Glycine max* (L.) Merr.] and corn (*Zea mays* L.) rotation. Soybean was the crop in 1997 and corn was the crop in 1998.

Field methodology. Precipitation was measured by a tipping bucket rain gauge with a CR10 data logger (Campbell Scientific, Logan UT) located in the riparian study area. Triplicate plots used in this study were installed in the multi-species riparian buffer system in April, 1997 with a 4.1 by 22.1 m (14 x 73 ft) cropland source area paired with either no buffer, a 7 m wide (23 ft) switchgrass filter, or a 16.3 m (53.5 ft) wide switchgrass/woody plant buffer located at the lower end of each plot. The source area for these plots was selected because it was large enough to represent the combined processes of rill and inter-rill erosion and because they are the size of the standard erosion plots used to develop the Universal Soil Loss Equation (Mutchler et al., 1994). Total buffer width of the widest buffer was 16.3 m (53.5 ft) instead of the 20 m (66 ft) of the actual buffers in the field because 3.7 m (12.2 ft) was needed to set up the collection apparatus for the plot. This width was taken out of the woody zone adjacent to the stream. The plots were isolated with sheet-metal borders driven into the ground with metal gutters and double-split runoff dividers installed at the down slope end for manual sample collection and flow

Figure 2
Model of the multi-species riparian buffer planted at the study site.



measurement. Collected runoff was routed through double-split runoff dividers, used in an earlier study (Lee et al., 2000) and similar to the runoff divider designed by Sombatpanit et al. (1990) (Figure 3). These dividers split the runoff from each plot with a 25:1 ratio. The water was collected in a tank and amounted to 4% of the total runoff generated in each plot during each rainfall event. Runoff samples were collected on the day of the rainfall event or on the next day following rainfall events. Multiple events occurring in a day were collected as one runoff sample. Water samples were pulled from the tank after 1 minute of agitation of the collected runoff water. The total runoff volume was determined by measuring the depth of water in the tanks. Runoff samples were collected in 1 L plastic bottles for particle size analysis and 0.5 L bottles for sediment and nutrient analysis. After sampling, the water tanks were cleaned out for the next runoff collection. To estimate the effectiveness of the multi-species riparian buffer, it was assumed that the amount of input to the plots with buffers was the same as the discharge amount from non-buffered plots in each set of plots.

Laboratory methodology. Aliquots of the runoff samples were filtered (0.45 mm pore diameter) for nitrate-nitrogen (NO_3-N) and phosphate-phosphorus (PO_4-P) analysis. The surface runoff samples were analyzed at the Department of Forestry Laboratory at Iowa State University for particle size, sediment, total-nitrogen (N), NO_3-N, total-phosphorus (P), and PO_4-P content by using standard procedures (Clesceri et al., 1989). Sediment in runoff samples was separated into 50, 20, 8, and 2 μm particle sizes using standard pipette procedures without chemical dispersion (Gee and Bauder, 1986). The amount of runoff, sediment, and nutrient concentration data were used to compute mass transport of each constituent occurring at the end of each plot.

Statistical analysis. General linear model tests were performed to determine the effects of the switchgrass and the switchgrass/woody buffer in runoff and the concentration and mass transport of the measured variables (SAS Institute, Inc., 1996). Least significant difference (LSD) tests were performed to determine differences at $P < 0.05$ in buffer treatments for all measured variables.

Precipitation and runoff. Total annual precipitation was 738 mm (29 in) in 1997, and 872 mm (34.3 in) in 1998. The total annual precipitation in 1997 was 12% below,

Figure 3
Schematic diagram of the plots and runoff collector (double-split runoff divider).

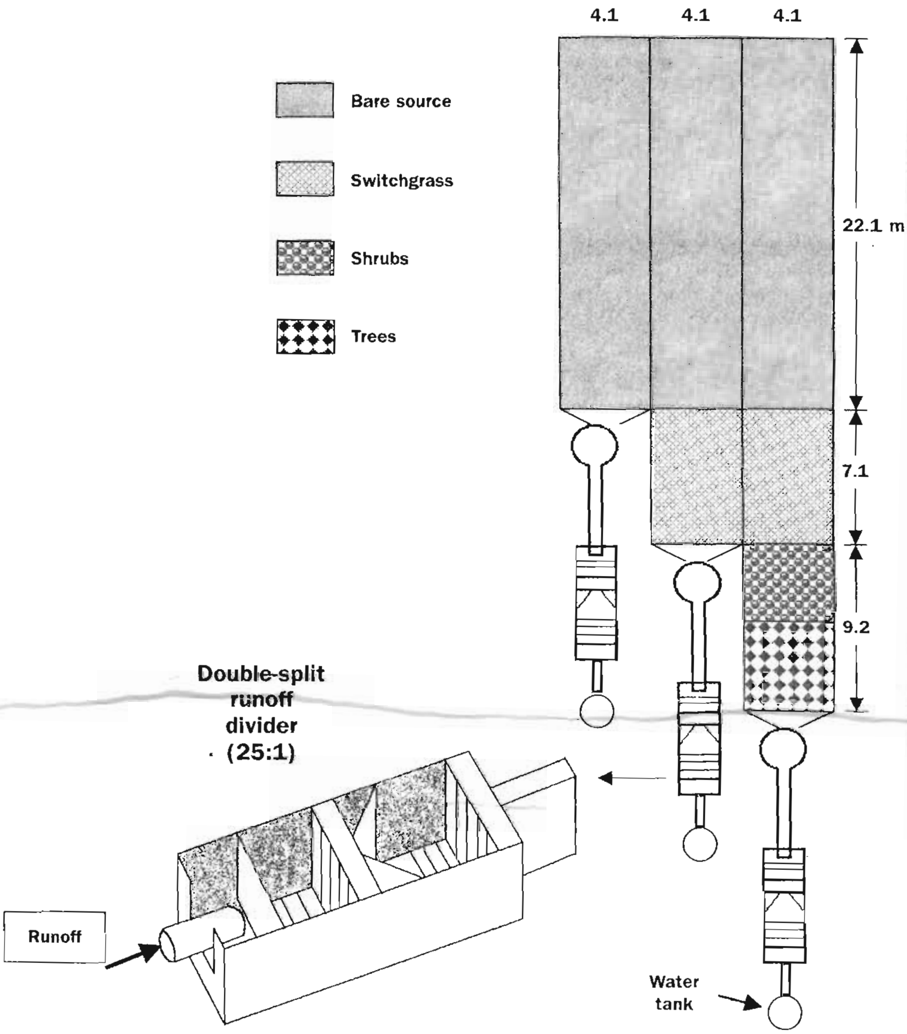


Figure 4
Rainfall events for 1997 and 1998 for Bear Creek in Story County, Iowa, USA (42° 11'N, 93° 30'W).

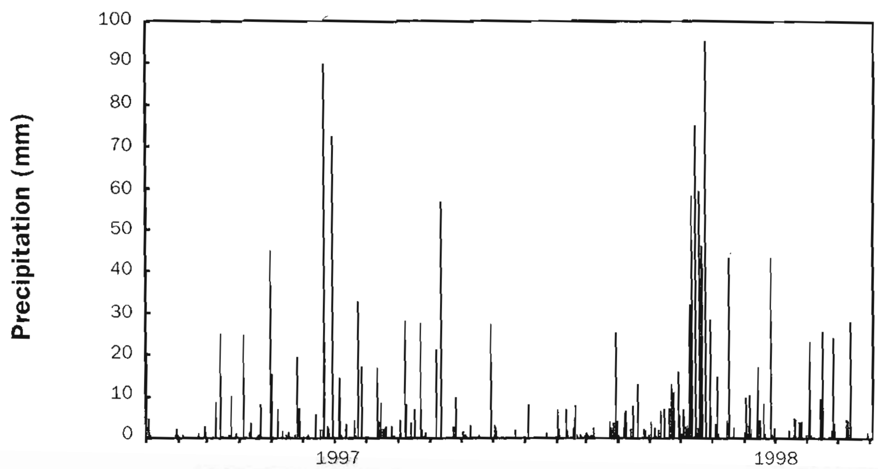


Table 1. Runoff and mass transport of sediment, total-nitrogen (N), nitrate-nitrogen (NO_3-N), total-phosphorus (P), and phosphate-phosphorus (PO_4-P) from non-buffered and buffered plots during 1997-1998. Each value is the mean of 19 precipitation events from three replicated plots. The cropland source area for each plot was 4.1 by 22.1 m (14 x 73 ft).

Buffer	Runoff mm	Sediment kg ha^{-1}	Total-N	NO_3-N	Total-P	PO_4-P
			g ha^{-1}			
None	9.7 a[†]	587.1 a	551.0 a	91.2 a	199.8 a	48.4 a
	(2.5)[§]	(302.2)	(159.9)	(27.0)	(56.6)	(10.5)
Switchgrass (7 m wide)	4.0 b	45.2 b	119.7 b	34.4 b	40.4 b	20.5 b
	(1.4)	(8.3)	(31.5)	(11.0)	(11.4)	(5.7)
Switchgrass/woody (16.3 m wide)	1.8 c	16.4 c	51.3 c	16.6 c	19.4 c	10.2 c
	(1.0)	(3.7)	(13.4)	(6.2)	(6.7)	(4.6)

† Values in the same column followed by a different letter are significantly different ($P<0.05$).

§ Values in parentheses are standard errors.

Table 2. Mean particle size distribution in runoff from non-buffered and buffered plots during 1997-1998. Each value is the mean of 19 precipitation events from three replicated plots. The cropland source area for each plot was 4.1 by 22.1 m (14 x 73 ft). The pipette method without chemical dispersion was used.

	Particle size (μm)				
Buffer	> 50 Sand	50-20	20-8 Silt	8-2	< 2 Clay
	%				
None	24.4	23.6	23.4	16.8	10.8
	(2.9)[†]	(2.3)	(1.1)	(1.6)	(1.9)
Switchgrass (7 m wide)	8.6	13.5	18.7	25.9	33.3
	(1.5)	(2.0)	(1.4)	(2.7)	(2.2)
Switchgrass/woody (16.3 m wide)	6.5	11.3	16.7	18.5	47.0
	(0.3)	(1.2)	(1.0)	(2.3)	(3.4)

† Values in parentheses are standard errors.

Table 3. Reduction of runoff and mass transport of sediment, total-nitrogen (N), nitrate-nitrogen (NO_3-N), total-phosphorus (P), and phosphate-phosphorus (PO_4-P), from non-buffered and buffered plots during 1997-1998. Each value is the mean of 19 precipitation events from three replicated plots. The cropland source area for each plot was 4.1 by 22.1 m (14 x 73 ft).

Buffer	Runoff	Sediment	Total-N	NO_3-N	Total-P	PO_4-P
	%					
Switchgrass (7 m wide)	58.3 a[†]	95.3 a	80.3 a	62.4 a	78.0 a	57.5 a
	(5.7)[‡]	(2.1)	(2.9)	(5.4)	(3.3)	(6.1)
Switchgrass/woody (16.3 m wide)	81.5 b	97.2 b	93.9 b	84.9 b	91.3 b	79.8 b
	(3.9)	(0.9)	(1.2)	(3.5)	(2.0)	(4.6)

† Values in the same column followed by a different letter are significantly different ($P < 0.05$).

‡ Values in parentheses are standard errors.

and the total annual precipitation in 1998 was 4% above the long-term average of 841 mm (33.1 in) for the study area. The number of rainfall events that resulted in at least 0.02 mm (0.008 in) of runoff at the study plots ranged from six in 1997 to 13 in 1998. The rainfall events that resulted in runoff from all plots in 1997 were relatively well distributed through the year compared with the rainfall events in 1998. In 1998, six major runoff events occurred in June (Figure 4).

Results and Discussion

The switchgrass and switchgrass/woody buffers reduced surface discharge of runoff, sediment and nutrients from the crop fields to the stream (Table 1). Sediment size has a dominant effect on trapping potential of buffers. The sediment from non-buffered plots was composed of 25% sand (> 50 μm), 64% silt (2-50 μm), and 11% clay (< 2 μm) particles (Table 2). Even though the percentages of a given size fraction of sediment varied among the rainfall events, the differences were not significant statistically. Buffers decreased the proportion of sand from 25% to 9% in the switchgrass buffer, and to 7% in the switchgrass/woody buffer, whereas buffers increased the proportion of clay from 11% to 33% in the switchgrass buffer, and to 47% in the switchgrass/woody buffer (Table 2). Under the natural rainfall events that generated surface runoff at the end of the buffers the 7 m (23 ft) wide switchgrass buffer removed > 92% of the sediment and the 16.3 m (53.5 ft) wide switchgrass/woody buffer removed > 97% of sediment (Table 3). The sediment reduction occurred primarily in the switchgrass buffer. The switchgrass/woody buffer had three times less sediment transported through it than the switchgrass buffer, which had 13 times less sediment transported through it than the non-buffered plots (Table 1). A rainfall simulation study conducted in the same area by Lee et al. (2000) showed a similar result that the switchgrass/woody buffer trapped more than 92% of the incoming sediment and the switchgrass buffer was effective in trapping coarse sediment and sediment-bound nutrients.

Sheridan et al. (1999) examined the management effects on runoff and sediment transport in riparian forest buffers in the coastal plain. The primary zone of sediment reduction was within the grass filter portion of their buffer system. The grass was harvested twice annually for biomass production.

Table 4. Runoff and mass transport of sediment, total- nitrogen (N), nitrate-nitrogen (NO_3-N), total-phosphorus (P), and phosphate-phosphorus (PO_4-P) from the 3 highest runoff events from each study year by chronological order.

Date	Rainfall	I_{30}	Buffer	Runoff	Sediment	TN	NO_3-N	TP	PO_4-P
	mm	mm h^{-1}		mm	kg ha^{-1}	g ha^{-1}			
6/29/97	72	78	None	27	49	2453	190	619	90
			Switchgrass	21	11	872	137	160	68
			Switchgrass/woody	14	7	383	89	93	65
7/6/97	39	49	None	9	20	416	45	139	78
			Switchgrass	6	3	92	29	51	33
			Switchgrass/woody	4	2	38	18	33	21
7/27/97	20	28	None	4	4	105	18	84	20
			Switchgrass	2	1	30	10	22	15
			Switchgrass/woody	< 1	< 1	5	2	2	3
6/11/98	58	37	None	23	1840	1298	373	460	142
			Switchgrass	9	77	261	117	91	58
			Switchgrass/woody	5	35	122	44	41	36
6/24/98	95	30	None	27	4919	1157	298	726	68
			Switchgrass	12	123	246	104	88	23
			Switchgrass/woody	7	54	123	52	36	20
7/17/98	43	35	None	9	532	278	63	150	47
			Switchgrass	4	10	75	23	27	22
			Switchgrass/woody	1	1	19	6	11	10

Note: 97 crop was soybean and 98 crop was corn.

Reductions of sediment transport across the grass filter portion of the buffer system ranged from 78 to 83%, and reduction of sediment across the grass filter plus mature forest buffer was 95% (Sheridan et al., 1999). Results from Sheridan et al. (1999) compared with those found in this study. The 5% slope in this study area was greater and the width of plots was narrower (7.1 m) than those in the Gulf-Atlantic Coastal Plain. However, the switchgrass buffer in this study reduced sediment transport over 10% more than the grass filter in the study conducted by Sheridan et al. (1999). The greater sediment reduction by the switchgrass buffer could be due to the differences in growth pattern between the cool-season grasses and the warm-season switchgrass, and the biomass harvesting in the coastal plain buffer may have reduced the effectiveness of sediment removal. The uniform distribution of the plants and large production of litter on the switchgrass buffer may be responsible for the high removal of sediment (Correll, 1997; Dabney et al., 1993; Lee et al., 1999). Particle size distribution in the surface runoff changed through the buffers indicating that there was a selective process in which large particles are deposited prior to small particles and more than 90% of the sediment in the surface runoff from the buffered plots was in the < 0.05 mm size fraction (Table 2). Alberts et al. (1981) showed that a 2.7 m long residue strip with 50% surface cover filtered out most of the particles > 0.05 mm, and 85% of the sediment leaving the residue strip was in the size fractions < 0.035 mm, which increased the nutrient concentrations of the surface runoff.

The buffers reduced the mass transport of total-N and NO_3-N, total-P, and PO_4-P in surface runoff from cropland. The average mass transport of total-N and NO_3-N, total-P, and PO_4-P were different (P <0.05) among buffer treatments (Table 1). Mean percentage mass reductions in N and P in surface runoff occurred through the buffers, with the greater mass reductions measured in the switchgrass/woody buffer (Table 3). The added width of the switchgrass/woody buffer reduced 23% more runoff, 2% more sediment, 14% more total-N, 23% more NO_3-N, 13% more total-P, and 22% more PO_4-P than the switchgrass buffer alone (Table 3). The results indicate that the 7 m (23 ft) wide switchgrass buffer alone was effective in removing sediment and sediment-bound nutrients, and the added woody buffer was effective in removing runoff and soluble nutrients. The importance of vegetation in buffers in improving soil structure and permeability is well known. Vegetation changes the soil structure by adding organic matter that improves aggregations and by creating root channels and thereby increasing the infiltration capacity (Marquez et al., 1999; Vought

Table 5. Correlation coefficients (Pearson) of buffer trapping effectiveness for runoff, sediment, total-nitrogen (N), nitrate-nitrogen (NO_3-N), total-phosphorus (P), and phosphate-phosphorus (PO_4-P) with total rainfall amount, and rainfall intensity (I_{30}) based on 19 single storm events during 1997 and 1998.

Buffer	Parameter	Total rainfall amount	I_{30}
Switchgrass (7 m wide)	Runoff	-0.53*	-0.71**
	Sediment	-0.36	-0.46*
	Total-N	-0.40	-0.67**
	NO3-N	-0.27	-0.47*
	Total-P	-0.35	-0.35
	PO4-P	-0.49	-0.54*
Switchgrass/woody (16.3 m wide)	Runoff	-0.72**	-0.79**
	Sediment	-0.29	-0.87**
	Total-N	-0.81**	-0.80**
	NO3-N	-0.59**	-0.75**
	Total-P	-0.51*	-0.48*
	PO4-P	-0.76	-0.77

****P*<0.05, ***P*<0.01**

et al., 1994). Infiltration of runoff in buffers may facilitate reduction of both sediment-bound nutrients with small particles and of soluble nutrients. During infiltration, sediment-bound nutrients may be sieved from the water through the soil profile (Dillaha et al., 1988). Furthermore, infiltration into the buffer soil decreases surface runoff, which in turn reduces the ability of the runoff to transport soil particles and particulate P (Dillaha et al., 1988). The lower runoff volume from the buffered plots is attributed to increased infiltration by the vegetation. Lee (1999) reported that total-N and total-P transport was associated with sediment in runoff. Dillaha et al. (1989) reported that 4.6 m (15 ft) and 9.1 m (30 ft) filter strips with shallow uniform flow removed an average of 74 and 84% of the incoming sediment, 54 and 73% of the incoming N, and 61 and 79% of incoming P, respectively. The removal of N and P from the runoff was nearly as effective as the sediment removal, and this was expected because 65 and 66% of the N, and 92 and 90% of the P leaving the 4.6 m (15 ft) and 9.1 m (30 ft) filter strips, respectively, was sediment-bound.

Mass reductions in sediment, nutrients, and runoff occurred in both the wet and dry year. The degree of runoff depends primarily on antecedent moisture conditions and the return period of rainfall events (Clinnick, 1985). While antecedent moisture was not measured as part of this study, the shorter time intervals between storm events in 1998 compared with those in 1997 may have contributed to a wetter soil environment resulting in more runoff from the plots (Figure 4). Because we kept track of each rainfall event we were able to observe differ-

Table 6. Reduction in runoff, sediment and nutrient from the 3 highest runoff events during each study year.

Date	Rainfall	I_{30}	Buffer	Runoff	Sediment	TN	NO_3-N	TP	PO_4-P
	mm	mm h^{-1}		g ha^{-1}					
6/29/97	72	78	Switchgrass	22	78	65	28	74	24
			Switchgrass/woody	48	86	84	53	85	28
7/6/97	39	49	Switchgrass	33	85	78	36	63	58
			Switchgrass/woody	56	90	91	60	76	73
7/27/97	20	28	Switchgrass	48	71	71	44	74	25
			Switchgrass/woody	91	95	95	89	98	86
6/11/98	58	37	Switchgrass	61	96	80	69	80	59
			Switchgrass/woody	78	98	91	88	91	75
6/24/98	95	30	Switchgrass	56	98	79	65	88	66
			Switchgrass/woody	74	99	89	83	95	71
7/17/98	43	35	Switchgrass	56	98	73	64	82	53
			Switchgrass/woody	89	99	93	91	93	79

Note: 97 crop was soybean and 98 crop was corn.

ences in buffer trapping effectiveness with different rainfall amounts and intensities (Table 4). As expected, the trapping effectiveness of the buffers was affected negatively by both total rainfall amount and rainfall intensity (I_{30}). Intensity had more effect on the trapping effectiveness than the total rainfall amount. There were significant correlations ($P<0.01$ and $P<0.05$)) between the trapping effectiveness and intensity for each of the variables in the two widths of buffers (Table 5). This means that as rainfall intensity increased the trapping effectiveness of the buffer for these variables was decreased. For all storms the trapping effectiveness for sediment did not fall below 71% for the switchgrass buffer or 86% for the wider switchgrass/woody buffer (Table 6). Except for the highest intensity storm (78 mm h^{-1}) trapping effectiveness for NO_3-N and PO_4-P remained above 60% for the wider switchgrass/woody buffer. Differences in the amount of sediment and nutrients trapped by the buffers in the two years can also be attributed to the differences in cropping. During 1997 the source areas were planted to soybeans. Planting was done early and a significant amount of corn residue covered the ground providing reasonable soil cover during the more widely spaced storm events. In 1998 the source areas were planted to corn and did not produce a very dense stand, so at the time of the earlier storm events less of the soil surface was covered. The young buffers were only in their fourth and fifth growing seasons during this experiment.

Summary and Conclusion

In summary, the switchgrass and switchgrass/woody buffers reduced surface discharge of runoff and mass transport of sediment and nutrients from the crop field to the stream. Under natural rainfall events that generated surface runoff at the end of the buffers, the 7 m (23 ft) wide switchgrass buffer removed > 92% of the sediment, and the 16.3 m (53.5 ft) wide switchgrass/woody buffer removed > 97% of the sediment. During one rainfall event in 1997 the difference in removal of sediment was 24% less in the narrower buffer. The wider switchgrass/woody buffer increased the removal efficiency of soluble nutrients by 20%. These results would suggest that the narrower switchgrass buffer alone is effective in removing sediment and sediment-bound nutrients but that the wider switchgrass/woody buffer adds a significant ability to also remove soluble nutrients in all but the most intense storm events (>75 mm hr^{-1}). Infiltration of runoff water into the soil profile and filtration of sediment by vegetation and organic litter on the buffers were the main mechanisms of nutrient removal from the runoff. Since native grass stands increase in density during the first 4 to 5 years and soil quality changes under the restored buffers is slow, further improvement of soluble nutrient removal can be expected in the future. These results suggest that there are major functional differences between narrow grass filters and wider mixed grass and woody plant buffers. The selection of one over the other should be based on the problems of each particular site.

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